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Sewage Research

THE VISCOSITY OR PSEUDO-PLASTIC PROPERTIES OF SEWAGE SLUDGES *

By W. D. Hatfield

Supt., Sanitary District, Decatur, Illinois

Introduction

The determination of viscosity of sewage sludges has received very little attention and viscosity data are seldom reported in the literature or used in engineering specifications where the flow of sludge is concerned. The importance of viscosity is illustrated in Poiseuille's viscous flow equation $\Delta P = 32\mu LV/gD^2$, Reynold's number $Re = DV\rho/\mu$, Fanning friction factor, $f = 16/Re = 16\mu/DV\rho$, all of which contain the symbol for viscosity, where μ = lbs./sec. ft. = $Z/1{,}488$, Z representing the absolute viscosity in centipoises.

Equations for the calculation of film coefficients of heat transfer in tanks of natural convection only, are of doubtful applicability. However if such calculations are attempted, our present knowledge would indicate the use of either the simple equation $h = 50\ (\Delta t^\circ/Z)^{0.33}$ or the more complicated functional relationship

$$hD/k = \phi\left(\frac{C\mu}{k}\right)\left(\frac{gD^3\beta\Delta t^\circ\rho^2}{\mu^2}\right).$$

This latter calculation is made by using Fig. 78 on page 138, *Elements of Chemical Engineering,* Badger and McCabe (1936). These equations emphasize the importance of a knowledge of viscosity of sludges, in the heat transfer field.

These fluid-flow and heat transfer equations are applicable to Newtonian or truly viscous fluids. In the case of non-Newtonian or plastic fluids our present knowledge is insufficient to properly formulate corrections, and the equations must be used for approximations only.

Nomenclature

Flow

ΔH_f = loss of head in feet = $\Delta P/\rho$.
ΔP = pressure loss or drop in lbs./sq. ft.
L = length in feet.
$V = u$ = velocity in ft./sec.
g = acceleration of gravity ft./sec.^{2}
D = diameter of pipe in feet.
D'' = diameter of pipe in inches.

* Presented at the Tenth Annual Convention of the Central States Sewage Works Association, St. Paul, Minn., Oct. 21, 1937.

f = Fanning friction factor.
ϕ = functional factor.
μ = viscosity, lbs./ft. sec. = $Z/1{,}488$.
Z = viscosity, centipoises.
s = specific gravity, grams/ml.[3]
ρ = density, lbs./cu. ft.
V_{1c} = lower critical velocity.

Heat Transfer

h = outside film coefficient, B.t.u./sq. ft./hr./° F.
k = thermal coefficient.
C = specific heat.
β = coefficient of thermal expansion.
$\Delta t°$ = temperature difference.

Viscometer

f' = apparent friction factor of viscometer.
Re' = Apparent Reynold's number of viscometer.
T = grams weight driving viscometer.
R = revolutions/minute.

Sewage sludge is a heterogeneous mixture of complex organic solids including some inorganic grits, the flow characteristics of which would not be truly viscous but plastic or pseudo-plastic. Williams,[1,2] Perry,[3] Jordan, Brass and Roe [4] and others have recently described the flow characteristics of Newtonian or viscous liquids, and non-Newtonian or plastic, pseudo-plastic or inverted plastic liquids. With viscous liquids the coefficient of viscosity is constant over a wide range of shearing stresses which do not exhibit turbulence. In non-Newtonian or plastic liquids pressure or shearing stress is necessary to overcome the *internal friction* of the material or solution before flow is started, in addition to the shearing stress due to the real viscosity of the liquid.[1]

The physical nature of sewage sludge precludes the use of the falling ball, orifice or capillary tube methods for determining shear-stress and viscosity relationships. The rotating cylinder method is adopted to such material. A Stormer Viscometer (1929) was available and preliminary studies were started in January, 1936. Although the data obtained with a Stormer Viscometer do not permit exact calculation of shearing stresses and rates of shear, this viscometer does give data from which "apparent" shear-stress diagrams may be plotted,[3] and data from which, after calibration of the viscometer according to Squires and Dockendorff,[5] the viscosity may be calculated at any particular driving force or stress. This calibration is based on the "apparent" *friction factor* and *Reynold's number* produced in the apparatus and allows the determination of viscosities in the turbulent, as well

1 R. V. Williams, *Ind. Eng. Chem.*, **21**, 1108–11 (1929).
2 R. V. Williams, *Ind. Eng. Chem.*, **21**, 1111–15 (1929).
3 J. H. Perry, *Chemical Engineering Handbook*, pp. 1271–7 (1934).
4 H. F. Jordan, P. D. Brass and C. P. Roe, *Ind. Eng. Chem. Anal. Ed.*, **9**, 182–9 (1937).
5 Lombard Squires and R. L. Dockendorff, *Ind. Eng. Chem. Anal. Ed.*, **28**, 295–7 (1936).

as the viscous, flow region. Using this calibration, viscosities approaching that of water are readily determined within an error of about 5 per cent.

Merkel has [6] made a study of the flow characteristics of Imhoff sludges at Stuttgart, Germany both in existing sludge lines and with a Kaempf rotational viscometer.[7, 8] From these data he developed curves showing the pseudo-plastic nature of sewage sludges, and suggested the possible application (to certain restricted regimes of flow) of Reiner's [6, 8] modification of Poiseuille's equation,

$$V \text{ in cm./sec.} = \frac{r^2 J\gamma}{800\mu}\left[1 - \frac{2.667\vartheta}{J\gamma r} + 5.33\left(\frac{\vartheta}{J\gamma r}\right)^4\right]$$

r = radius in cm., J = loss of head, γ = density in g./cm.^{3}, μ = viscosity in g. sec./cm.^{2}, ϑ = resistance of material in g./cm.^{2},

to sludges of from 80 to 88 per cent moisture with good approximation. Merkel called attention to the fact that the material is thixotropic, *i.e.* it loses much of its plastic resistance on stirring or mixing, and also that as the lyophilic particles increase the viscosity increases, and that increases in lyophobic material have no large effect on the viscosity but increase the internal resistance and the yield point.

E. R. Queer,[9] in an article on heat transfer in sludge, states "by the falling ball method it (the viscosity) was found to be about 1,000 times that of water." No further data on the sludge is given regarding solids, ash or specific gravity.

A Committee of the American Society of Civil Engineers [10] concluded that the laws of fluid-flow did not apply to sewage sludge because it was so variable in properties and the Committee therefore contented itself with the accumulation of much valuable data on friction losses in existing sludge lines in England and America. Much of the data on sludge is lacking in some essential such as velocity, friction loss or per cent moisture and seldom is the specific gravity (density), per cent organic matter or viscosity available. The Committee presented some very valuable data on friction losses of Imhoff sludge flowing, particularly, in 8 inch pipes (some of the data in 12 inch pipes were admittedly unexplainable) which were determined by the Sanitary District of Chicago at the Calumet Works. On the other hand Clifford [11, 12] pointed out that the laws of flow hold with sufficient approximation to yield valuable data. He assumed, from tests on sludges of 90 per cent moisture and glycerin, a kinematic viscosity of 0.001055 for such sludges. Applying this assumed viscosity to the data for sludge of 90 per cent moisture flowing in 8-inch pipes at Calumet, Clifford cal-

6 Wilhelm Merkel, *Physics*, **5**, 355–61 (1934).
7 Kaempf-Schrenk, *Koll. Zeits.*, **51**, 165.
8 McMillen, *J. Rheology.*, **3**, 76, 163, 179 (1932).
9 E. R. Queer, *Sewage Works J.*, **5**, 937–44 (1933).
10 Committee Am. Soc. Civil Engrs., *Proc. Amer. Soc. Civil Engr.*, **55**, 1773–97 (1929).
11 William Clifford, *Trans., Int. Conference on Sanitary Eng.*, 1924, p. 59.
12 William Clifford, *Proc. Amer. Soc. Civil Engr.*, **56**, 821 (1930).

culated theoretically the friction losses. These calculated losses checked so well with those observed at Calumet that Clifford wrote, "In the light of the relationships described the writer would suggest that *further attempts be made to explore* the various ways of measuring the *physical qualities of sludges* and to correlate these with friction losses obtained in practice. . . ." In the following paper the author attempts to present some data on the physical properties of sludge that pertain to its properties of flow and resistance to flow.

Preliminary Laboratory Work

The Stormer Viscometer with the standard cup containing two vanes could not be used with sewage sludges because grit and other small solids caught between the rotating cylinder and the vanes. Therefore it was necessary to replace the standard cup with a vaneless cup having sufficient distance between the cup wall and the rotating cylinder to insure free passage of bulky solids. Different sizes of beakers were tried in place of the standard cup, using a heavy digested sludge with the following results:

Beaker, Vol. in Ml.	Beaker, Dia. in Cm.	Clearance in Cm.	Driving Weight	Cylinder, Rev./Sec.
50	4	.435	150 g.	1.72
150	5.4	1.125	150	1.25
250	6.5	1.675	150	1.13
600	8.4	2.625	150	1.13

After numerous tests the 150 ml. beaker was adopted as standard because the clearance was large enough to pass rather large bulky solids and still small enough to show an effect of the outer wall on the speed of the revolving cylinder. The results obtained with the 150 ml. beaker are quite reproducible on sludge samples except when sticks or hard fibrous materials interfere with the rotation.

Standardization.—The Stormer Viscometer with the 150 ml. beaker was standardized at 20° C. with the following solutions of known viscosities: (1) a heavy oil, 2,100 centipoises (cp.) which was standardized by the U. S. Bureau of Standards, (2) glycerin, 410 cp., (3) 68, 65, 60, 40, and 20 per cent sucrose solutions having respective viscosities of 315, 135, 57, 6.2 and 1.9 cp.[13]

The friction of the viscometer was balanced with a hook, used for attaching the weights to the cord, that hardly overcame the friction of the machine when operating in air. With this particular machine the hook weighed 5.5 grams and would turn the cylinder in air without stalling when half of the cord length was unwound and functioning in addition to the weight of the hook. The *procedure* followed was to fill the 150 ml. beaker to within about 12 mm. of the top, submerge the cylinder 10 mm. below the surface of the liquid and center the cylinder

[13] International Critical Constants Tables, Vol. 2, 343 and Vol. 5, 23.

TABLE I.—*Standardization of Stormer Viscometer Using 150 Ml. Beaker*

Standard Solution	*T* Grams	Rev./Sec.	*R* = Rev./Min.	$f' = T/sR^2$	$Re' = Rs/.01\ Z$
Heavy oil					
Z = 2,100 cp.	20	0.046	2.76	2.19	0.114
s = 0.8946	50	.178	10.67	.454	.441
	100	.37	22.2	.221	.916
	200	.767	46.0	.1058	1.90
	300	1.18	70.7	.0677	2.92
	400	1.6	96	.0492	3.82
	500	2.02	121	.0389	5.00
	600	2.56	153.5	.0291	6.33
Sucrose 67.8 per cent	20	.445	26.7	.0149	12.8
Z = 315 cp.	50	1.29	77.5	.00553	34.0
s = 1.3425	70	1.80	108	.00412	46.0
	100	2.6	156	.00290	65.0
	200	5.15	309	.00152	128
Sucrose 65 per cent	15	.68	40.8	.00434	39.8
Z = 135 cp.	20	.98	58.8	.00318	56.4
s = 1.316334	25	1.28	76.8	.00251	74.8
	30	1.59	95.4	.002045	93.0
	40	2.18	131	.00153	128
	50	2.82	169	.00118	165
	60	3.27	196	.001106	191
	70	3.80	228	.000941	222
	90	4.67	280	.000819	273
	100	5.13	308	.000755	300
	120	5.98	359	.000673	350
	150	6.95	417	.000630	407
Sucrose 60 per cent	10	.646	38.8	.00233	87.5
Z = 57 cp.	15	1.52	91.2	.00089	206
s = 1.286456	20	2.12	126.1	.000709	285
	25	2.61	156.5	.000618	353
	30	3.00	180	.000588	406
	40	3.71	223	.000538	503
	50	4.35	261	.000510	589
	70	5.48	329	.000463	742
	100	7.1	426	.000403	962
Sucrose 40 per cent	10	2.25	135	.0002095	2,565
Z = 6.2 cp.	15	3.65	219	.000168	4,160
s = 1.176447	20	4.70	282	.000156	5,360
	25	6.70	402	.0001025	7,630
Sucrose 20 per cent	7	1.58	94.7	.000151	5,250
Z = 1.9 cp.	9	2.63	158	.0001275	8,740
s = 1.080959	10	2.98	179	.000127	9,880
	15	4.74	285	.000106	15,780
	20	6.10	366	.000098	20,250
Glycerin	50	.93	55.8	.01145	16.85
Z = 410 cp.	100	1.90	114	.00585	34.4
s = 1.2456	200	3.80	228	.00300	69.3
	300	5.59	335	.002112	102
	400	7.44	447	.001582	136

in the beaker with care. A small weight was placed on the hook and after waiting 5 to 10 revolutions for the cylinder to come up to speed, the number of seconds for 100 revolutions of the cylinder was determined with a stop watch. Similar determinations with heavier weights were made and recorded.

The standardizing data obtained in this manner, and the "*apparent* friction factors and Reynolds Numbers" are found in Table I. The latter data are calculated by the following equations;[5] apparent friction factor, $f' = T/sR^2$, and the apparent Reynolds Number, $Re' = Rs/0.01Z$, where T = grams producing shearing stress, s = specific gravity in grams/ml.[3], R = revolutions per minute of cylinder and Z = viscosity in centipoises.

In Fig. 1 the shearing stress, represented by T in grams, is plotted against the rate of shear expressed in revolutions per second of the rotating cylinder. The more viscous standards (300 to 2,100 centipoises) plot as straight lines which are characteristic of viscous liquids in the viscous flow region. The less viscous standards exhibit a curve of decreasing rate of shear at higher stresses which is due to the fact that at higher speeds the flow is in the turbulent region. This is characteristic of rotational viscometer data and is compensated for in calculating viscosities by use of the Squires-Dockendorff calibration curve[5] shown in Fig. 2. The data from which this curve is drawn are given in Table I.

The viscosity of an unknown solution (sludge in this case) is determined from the viscometer data by calculating the *apparent* friction factor f', obtaining the *apparent* Reynolds number Re' from the calibration curve in Fig. 2 and calculating the viscosity from the equation, $Z = 100\ Rs/Re'$.

Thixotropic Property.—It was found that only one run consisting of 10 to 100 revolutions of the cylinder could be made on a single beaker full of sludge, because each additional run on the same sample increased in speed, thus decreasing the viscosity or plastic resistance of the sludge. This *thixotropic* property, first mentioned by Merkel,[6] is very important and must be considered both in the determination of the viscosity of sludges and in the application of the viscosity data to engineering problems, because (1) it is impossible to obtain a sample of quiescent sludge and get it into the viscometer beaker without some slight agitation or stirring and (2) during each 100 revolutions of the viscometer cylinder the velocity of revolution has accelerated slightly with each revolution. This acceleration is particularly noticeable at very slow velocities on thick sludges, in which cases only 10 to 20 revolutions are timed.

For these reasons the viscosity of sludge as determined must be somewhat lower than that of the quiescent sludge in the digestion tank. The viscosity of sludge collected from the discharge of a sludge pump should be less than that of the sludge just moving into the suction line. Also the viscosity is calculated from the average revolutions per second,

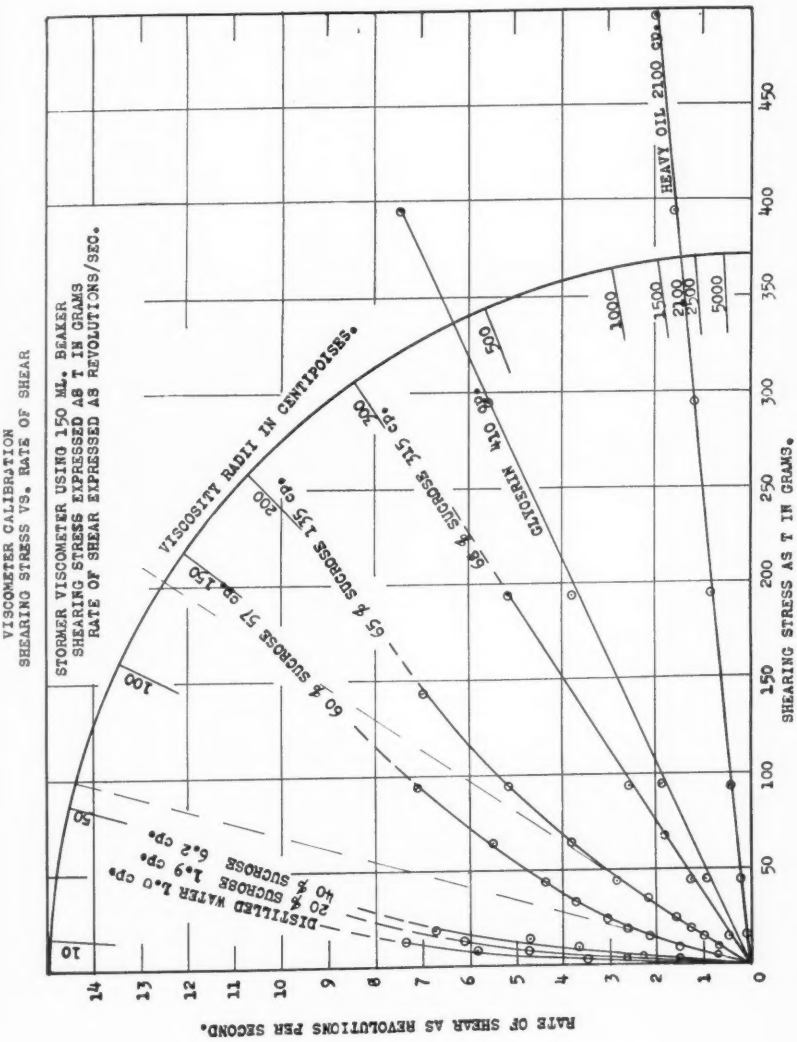
VISCOMETER CALIBRATION
SHEARING STRESS VS. RATE OF SHEAR
STORMER VISCOMETER USING 150 ML. BEAKER
SHEARING STRESS EXPRESSED AS T IN GRAMS
RATE OF SHEAR EXPRESSED AS REVOLUTIONS/SEC.
VISCOSITY RADII IN CENTIPOISES.
DISTILLED WATER 1.0 cp.
20 % SUCROSE 1.9 cp.
40 % SUCROSE 6.2 cp.
60 % SUCROSE 57 cp.
65 % SUCROSE 135 cp.
68 % SUCROSE 315 cp.
GLYCERIN 98 %
HEAVY OIL 2100 cp.
RATE OF SHEAR AS REVOLUTIONS PER SECOND.
SHEARING STRESS AS T IN GRAMS.

FIG. 1.

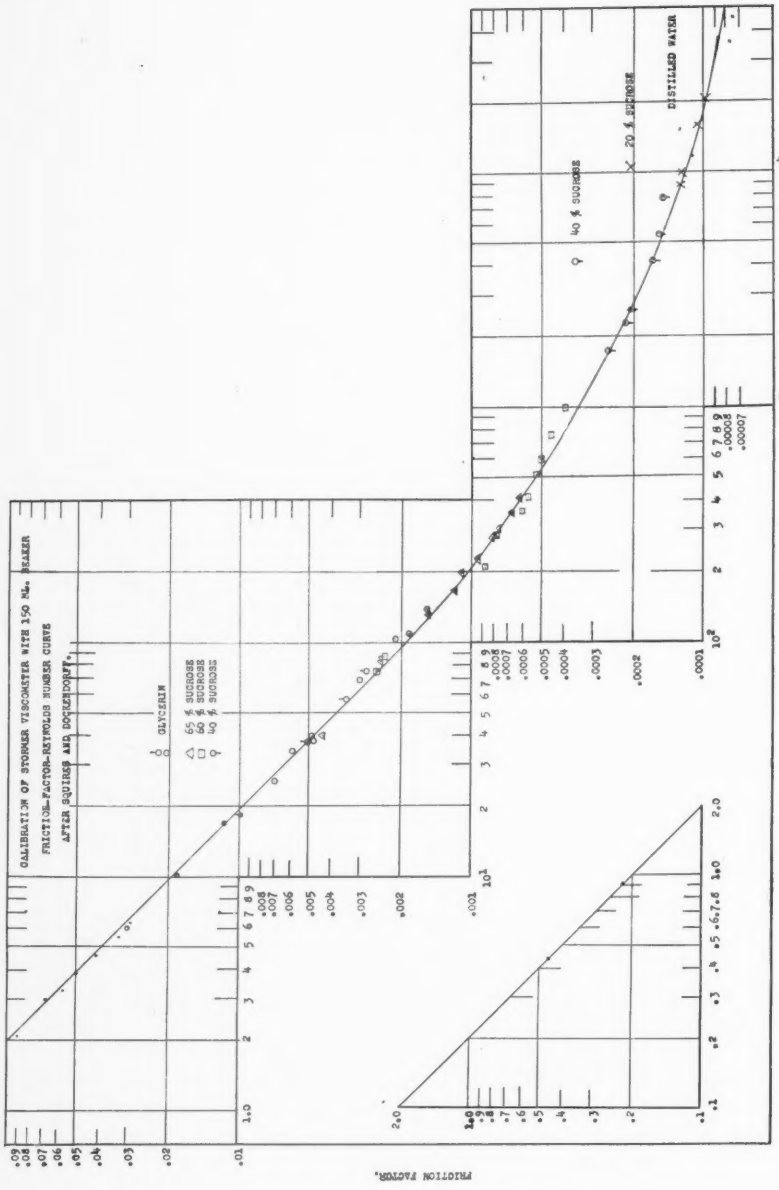
CALIBRATION OF STORMER VISCOMETER WITH 150 Nd. BEARER
FRICTION-FACTOR-REYNOLDS NUMBER CURVE
AFTER SQUIRES AND DOOLITTLE
GLYCERIN
65 % SUCROSE
60 % SUCROSE
40 % SUCROSE
40 % SUCROSE
20 % SUCROSE
DISTILLED WATER
FRICTION FACTOR.
REYNOLDS NUMBER.

FIG. 2.

timing 10 to 20 revolutions at speeds from 0.1 to 0.5 rev. per sec., and 100 revolutions at speeds above 0.5 rev. per sec. Within these speeds the acceleration is not noticeable to the eye although it is present to a degree.

In Fig. 3 the decreasing viscosities of three types of sludges are plotted against successive runs of 100 revolutions of the cylinder in the

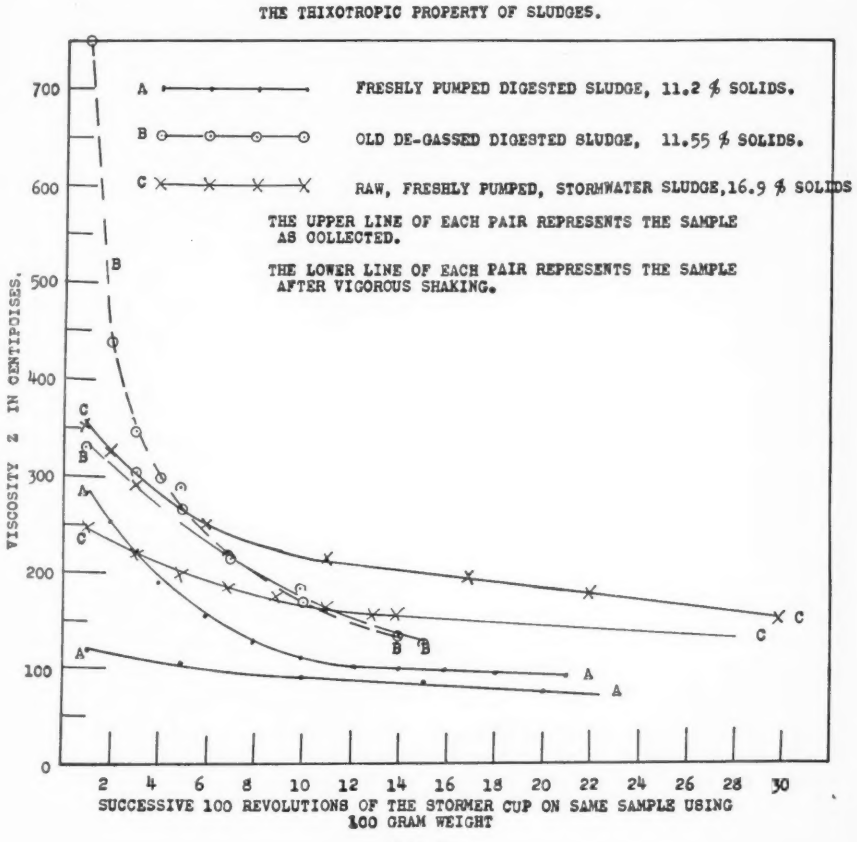
THE THIXOTROPIC PROPERTY OF SLUDGES.
A FRESHLY PUMPED DIGESTED SLUDGE, 11.2 % SOLIDS.
B OLD DE-GASSED DIGESTED SLUDGE, 11.55 % SOLIDS.
C RAW, FRESHLY PUMPED, STORMWATER SLUDGE, 16.9 % SOLIDS
THE UPPER LINE OF EACH PAIR REPRESENTS THE SAMPLE AS COLLECTED.
THE LOWER LINE OF EACH PAIR REPRESENTS THE SAMPLE AFTER VIGOROUS SHAKING.
VISCOSITY IN CENTIPOISES.
700
600
500
400
300
200
100
0
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
SUCCESSIVE 100 REVOLUTIONS OF THE STORMER CUP ON SAME SAMPLE USING 100 GRAM WEIGHT

FIG. 3.

same sample of sludge, using a 100 gram weight each time. For each type of sludge there are two lines, the upper line representing results on the sample of sludge as collected and the lower line representing the results on another sample of the same sludge after vigorous shaking for three minutes. The curves show also the differences in viscosity of sludges of somewhat similar moisture content but different in conditions of sampling. The old de-gassed sludge *B* was the same sludge as the freshly pumped sludge *A* except that it stood around the laboratory for 14 days, had stopped gassing and was sampled by carefully pouring directly into the 150 ml. beaker with as little agitation as possible.

Reproducibility of Results.—Although the viscosity obtained by this technic must be somewhat lower than that existing in the undisturbed sludge in the tanks, the results are quite reproducible, considering the nature of the material and the sampling error due to the necessary lack of stirring. The following results indicate the variation in seven individual determinations on the unstirred samples of sludge *A* in Fig. 3, using a 100 gram weight:

Rev./Sec.	f'	Re'	Z	Deviation	
				$\pm Z$	$\pm$ Per Cent
3.0	.002975	63	296	+16	+ 5.7
3.33	.00241	79	263	−17	− 6.1
3.18	.00264	72	275	− 5	− 1.8
3.16	.00269	70	281	+ 1	+ 0.36
3.50	.00219	87	251	−29	−10.3
3.29	.00248	77	284	+ 4	+ 1.4
2.83	.00355	53	310*	+30 *	+10.7 *
AVERAGE OF 7 results			280		

* A small twig was found pressing on the cylinder during this test.

Many results on other sludges indicate that the above maximum deviation of $\pm$ 10 per cent is a reasonable limit within which the data will fall.

Further studies of the thixotropic property were made using a thick well digested sludge (85.08 per cent moisture, 14.92 per cent solids, 64 per cent ash, specific gravity of 1.06). This sludge was stirred for 0, 5, 10, and 120 minutes with a laboratory mixer at a rate of 3,000 r.p.m. If the data obtained are plotted as in Figs. 5 and 6; that for the unstirred sludge practically coincides with Curve I for a similar sludge of 14.82 per cent solids; after 5 minutes stirring the same sludge very nearly coincides with Curve II of a similar sludge with 13.3 per cent solids; after ten minutes stirring the data plot about half-way between Curves II and III; and after 120 minutes stirring the plastic resistance has been reduced so that the curve practically coincides with Curve III, which represents a similar sludge with a solids content of 11.72 per cent. A shear-stress plot of these data, similar to Fig. 5, indicates that the rapid stirring breaks down the plastic or internal resistance of the sludge thus decreasing the "yield point," but leaving the truly viscous portion of the pseudo-plastic curves almost parallel in each case. The true viscosity of the sludge was only slightly affected and was about 100 centipoises. The data are not sufficient on which to base generalizations, but the indications are that the plastic resistance is the resistance which increases the "apparent viscosity" of the non-stirred sludges to form 1,000 to 5,000 centipoises at low shearing stresses, or low rates of shear.

Temperature Effect.—The effect of temperature on the "apparent viscosity" of sludge is shown in Fig. 4 *A–B*. The lines in Fig. 4*A*

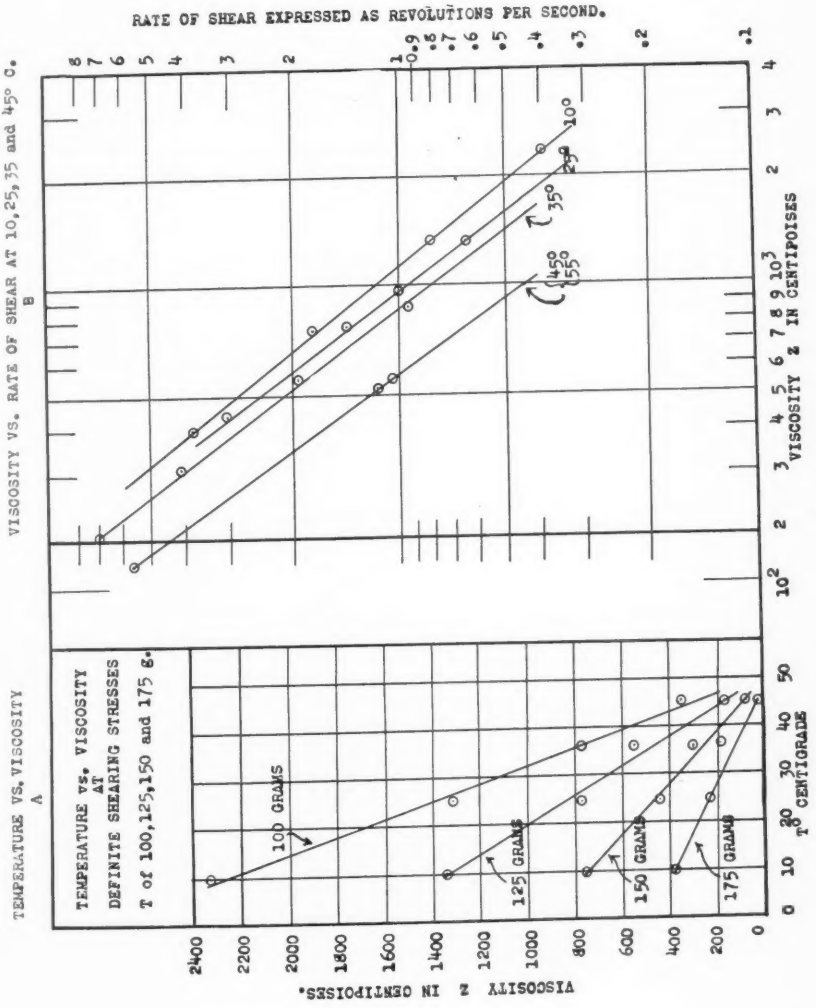
RATE OF SHEAR EXPRESSED AS REVOLUTIONS PER SECOND.
VISCOSITY VS. RATE OF SHEAR AT 10, 25, 35 and 45° C.
B
VISCOSITY Z IN CENTIPOISES
10°
25°
35°
45°
55°
TEMPERATURE VS. VISCOSITY
A
TEMPERATURE vs. VISCOSITY AT DEFINITE SHEARING STRESSES T of 100, 125, 150 and 175 g.
100 GRAMS
125 GRAMS
150 GRAMS
175 GRAMS
VISCOSITY Z IN CENTIPOISES.
T° CENTIGRADE

FIG. 4.

show that at a definite shearing stress (pulling weight) increases in temperature reduce the "apparent viscosity," rapidly for the low shearing stresses and less rapidly for higher stresses and higher rates of flow. In Fig. 4*B* the "viscosity-rate of shear" data are plotted on logarithmic coordinates, straight parallel lines being produced which clearly show the temperature-viscosity relation at definite rates of shear.

The data at 45° C. were not very satisfactory but serve to show another condition which affects the viscosity of sludge. In raising the temperature of the sludge to 45° C. it was accidentally heated to 55° C. and then reduced to 45° C. This procedure "de-gassed" the sludge and a large decrease in apparent viscosity is indicated in Fig. 4*B* by the wide displacement of the 45° C. line to the left. Another sample of the same sludge was very carefully raised to 45° C. At this temperature many small bubbles were released and held within the sludge,

TABLE II.—*The Viscosity of Digested Decatur Sludge of Varying Moisture Content*

Each determination on a separate unstirred sample

Sample				Viscometer Data					
No.	Solids Per Cent	Ash Per Cent	Sp. G. *s*	*T* Grams	Rev./ Sec.	Rev./ Min.	$f' = T/sR^2$	*Re'* (curve)	$Z = 100\ Rs/Re'$
I	14.82	62.70	1.075	120	0.184	11.1	.915000	0.22	5,400 cp.
				175	.583	35	.133000	1.5	2,510
				200	1.0	60	.0517	3.75	1,720
				275	3.43	205.5	.00605	32	690
II	13.34	63.15	1.065	80	.322	19.3	.2000	1.0	2,030
				120	1.045	62.75	.0286	6.8	885
				150	2.78	166.6	.00507	37.5	475
				180	5.3	318	.00167	117	290
III	11.72	64.4	1.051	40	.379	22.7	.0725	2.68	903
				50	1.146	68.8	.00975	19.5	376
				75	5.18	311	.000725	318	105
				100	7.88	473	.00042	720	70
IV	10.37	63.7	1.045	20	.245	14.7	.0878	2.2	705
				25	.413	24.75	.0387	5.00	523
				30	1.86	111.5	.00229	84	140
				50	5.78	347	.000394	800	46
				60	6.63	397.5	.00036	940	45
V	9.15	63.95	1.041	15	.556	33.4	.0128	15	233
				20	2.53	151.5	.00083	268	59
				30	4.77	286	.00045	640	47
VI	8.22	63.75	1.040	10	.29	17.6	.0312	6.2	295
				15	3.2	191.8	.000392	810	25
				20	3.98	239	.000351	980	25
				30	5.56	333	.00026	1660	21

thus increasing the viscosity so that when plotted in Fig. 4*B* a line coinciding with the 25° C. line was produced. An increase in temperature may release gas into the sludge, thus entirely overcoming any reduction in viscosity due to the temperature effect alone.

Solids Content and Viscosity.—A series of six sludges with solids contents from 14.82 to 8.22 per cent were made up by settling a large sample of digested sludge from the Decatur Plant, siphoning off the supernatant liquor, and carefully remixing the supernatant and settled sludges in varying amounts. Extreme care was taken to mix the samples thoroughly but with as gentle agitation as possible and to mix all samples in exactly the same way. The complete data on the sludges and the viscometer determinations are given in Table II. The sludge was a highly mineralized sludge, the ash varying from 62.17 to 64.4 per cent and the specific gravity from 1.075 to 1.040. The apparent viscosities Z expressed in centipoises vary from 690 to 5,400 for Sample I of 14.82 per cent solids down to from 21 to 295 for Sample VI of 8.22 per cent solids. The shear-stress data are plotted in Fig. 5. These curves emphasize the increase in plastic resistance with increase in solids content. After passing through the plastic or curved portions of the shear-stress curves, a straight line is obtained which represents the true viscosity of the solution after the break down of the plastic properties. This break down of plastic or pseudo-plastic resistance is probably "due to a progressive orientation of the particles to parallelism with the lines of liquid flow and the consequent release of interlocked liquid."[3] The straight-line portions of these curves, and those of the Springfield sludges also in Fig. 5 exhibit a parallelism indicating, at least qualitatively, that the true viscosities of all the sludges are very similar (*i.e.* 25 to 100 cp.). Increases in solids content largely affect the plastic resistance, which is most evident at low rates of shear and shearing stress.

The curves for the thinner sludges exhibit turbulent flow characteristics as shown by their convex position and will not give the apparent viscosity by prolonging a line from the origin through a point on the curve. This turbulent effect is to be expected with rotational viscometers when solutions of low viscosities are used.[5]

Raw, Digested and Activated Sludges.—Samples of raw, digested and activated sludges from the Springfield, Illinois, plant were collected and viscosities determined within one to two hours. The sludges were then concentrated over night, the supernatant siphoned off either from above or below and the top or bottom samples analyzed in order to get the effect of greater solids content on each sludge. The data are given in Table III and Figs. 5 and 6 and are similar to those on the digested sludges from Decatur. The viscosities were relatively higher on the Springfield sludges of a given solids content than on Decatur sludges of the same solids content.

The Springfield sludges had a higher organic matter content and a much lower solids content than the digested sludges from Decatur. For example the concentrated activated sludge No. XI (solids 2.75

per cent, ash 43.85 per cent, volatile solids 56.15 per cent) had plastic and viscous properties lying between No. III and IV of the Decatur sludges (solids 10.37 to 11.72 per cent, ash 63.7 to 64.4 per cent, volatile solids 36.3 to 35.6 per cent). The digested sludge No. VIII from Springfield (solids 8.30 per cent, ash 58.25 per cent, volatile solids 41.75 per cent) had almost identical flow properties as the No. II

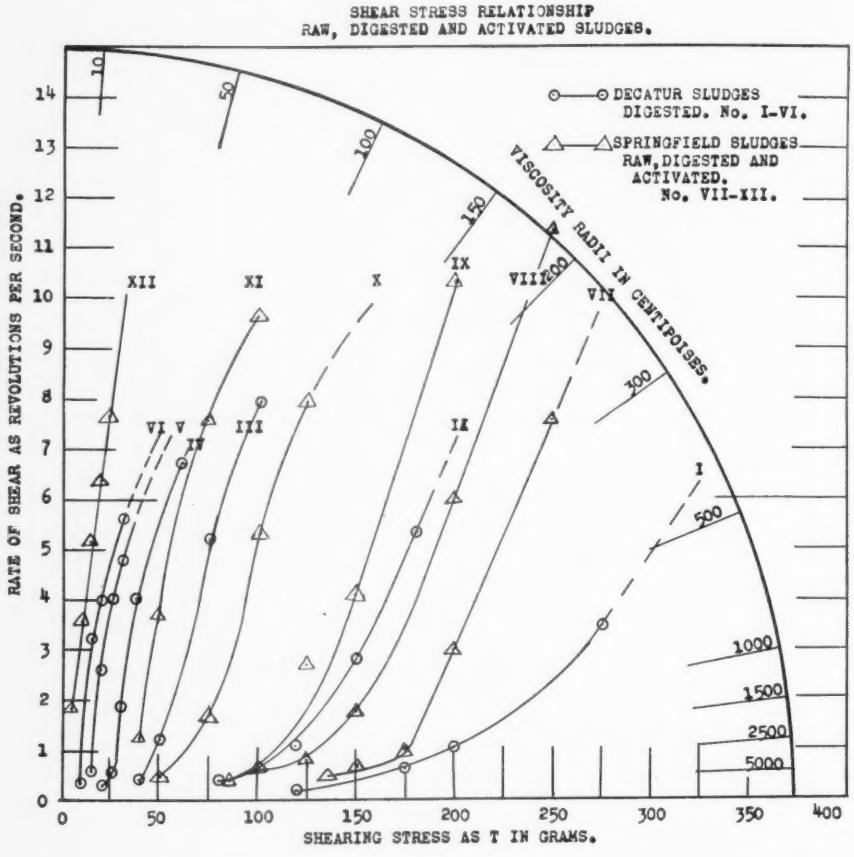

FIG. 5.

Decatur sludge (solids 13.34, ash 63.15, volatile solids 36.85 per cent). The data show clearly that the organic matter with its water-binding properties is the chief factor governing the plastic and viscous flow properties of the sludge, the inorganic constituents playing only a minor role. These properties are apparently due to a gel-like formation of the organic colloids which may be broken up by dilution or by stirring.

Although these *"rate of shear-shearing stress"* curves show quite clearly the plastic flow characteristics of the different sludges, it is hard to compare the variable apparent viscosities without some refer-

TABLE III.—*The Viscosity of Springfield Primary, Digested and Activated Sludges*

Each determination on a separate unstirred sample

Sample				Viscometer Data					
No.	Solids Per Cent	Ash Per Cent	Sp. G. s	T Grams	Rev./ Sec.	Rev./ Min.	$f' = T/sR^2$	Re' (curve)	$Z = 100\ Rs/Re'$
				Digested Sludge Concentrated					
VII	8.87	56.80	1.029	135	.452	27.1	.178	1.12	2,485 cp.
				150	.65	39	.096	2.03	1,975
				175	.814	48.8	.0715	2.65	1,890
				200	2.93	176	.00628	30	603
				250	7.52	452	.001195	169	272
				Digested Sludge as Drawn					
VIII	8.30	58.25	1.021	100	.588	35.25	.0787	2.45	1,470
				125	.704	42.25	.0650	3.0	1,435
				150	1.73	103.8	.0142	13.5	785
				200	6.06	364	.00148	132	281
				Primary Sludge (Inc. Activated Sludge) Concentrated					
IX	5.74	47.10	1.011	85	.35	21	.191	1.03	2,115
				100	.60	36	.076	2.9	1,255
				125	2.7	162	.00454	34.8	470
				150	4.05	243	.00251	75	328
				200	10.3	619	.000517	510	123
				Primary Sludge (Inc. Activated Sludge) as Drawn					
X	5.16	46.40	1.008	50	.408	24.5	.0827	2.35	1,050
				75	1.648	98.8	.0076	25	398
				100	5.26	316	.000992	210	151
				125	7.94	476	.000548	475	101
				Activated Sludge Concentrated					
XI	2.75	43.85	1.010	40	1.256	75.4	.00697	27.2	280
				50	3.71	222.5	.00100	210	107
				75	7.58	464	.00036	940	50
				100	9.62	577	.000297	1,300	45
				Activated Sludge as Drawn					
XII	1.28	44.00	1.002	5	1.8	109	.000456	630	17.3
				10	3.575	214.5	.000217	2,300	9.3
				15	5.15	308.5	.000150	5,400	5.7
				20	6.37	382	.0001368	6,800	5.6
				25	7.69	462	.000117	11,000	4.2

ence points of shear or stress. The *shearing stress* T in grams does not lend itself as a reference because no single weight is applicable to all sludges. On the other hand the *rates of shear* are common to all the sludge curves, and also the rate of shear or rate of flow is a logical point of reference, from an engineering point of view, in comparing the

viscosities of different sludges. For example, under practical conditions the velocity is more or less constant due to the limitations of the pump capacity and the diameter of the sludge line. Therefor the *viscosity-rate of shear* relationship has been plotted on logarithmic coordinates in Fig. 6 from which all sludges may be easily compared at definite velocities represented by 1, 2, 3 etc. revolutions per minute of the rotating cylinder.

Considering the errors inherent in the sampling of the sludge and the technic of the determinations it was a pleasant surprise to find how well the data plotted as parallel straight lines, the slopes of which are recorded in the figure. Except for the thicker sludges the slopes are -1.1 to -1.2, the slopes of the thicker sludges being about -1.4. Therefore the viscosity-rate of flow relationship is represented by the equation $x = a\ y^n$ where x = viscosity, y = rate of flow, $n = -1.1$ to -1.4 and a = a constant which depends on the per cent of organic matter, the per cent moisture or solids and other properties such as the decrease in resistance due to stirring.

Viscosity and Per Cent Solids.—The relationship of apparent viscosity to the solids content in sludges of different organic composition is indicated by the spacing "*a*" to the right or left of the parallel lines in Fig. 6. In the study of colloidal clay suspensions, the viscosity or fluidity is often plotted against the per cent solids. Such a plot can only be made with sludge data if we again limit the viscosities to those at a definite rate of shear. In Fig. 7 the apparent viscosities at one revolution per second of the cylinder and the per cent solids of the Decatur and Springfield sludges are plotted on logarithmic coordinates. A straight and parallel line relationship is again obtained although in this case the slope is + instead of — as in Fig. 6.

Some interesting comparisons of the sludges can be made from Fig. 7. For example, take a constant viscosity of 500 cp. at 1 revolution per second. A Decatur digested sludge of 11.8 per cent solids would have this viscosity; a Springfield digested sludge of 6.7 per cent, a Springfield primary sludge of 4.8 and an activated sludge (by extrapolation) of 3.1 per cent would have the same viscosity. It is perhaps not justifiable to extrapolate these curves too far. However, just as a matter of interest, if the various curves are extended and compared at a concentration of 5 and 10 per cent solids the following viscosities at one revolution per second are obtained:

	Viscosities in Cp.	
	5 Per Cent Solids	10 Per Cent Solids
Decatur digested sludge	9.5	225
Springfield digested sludge	180	2,000
Springfield primary sludge	580	6,000
Springfield activated sludge	2,350	21,000

Although these figures may not be at all reliable, because of extrapolation, they serve a purpose in showing the wide differences in viscosity of sludges of different compositions.

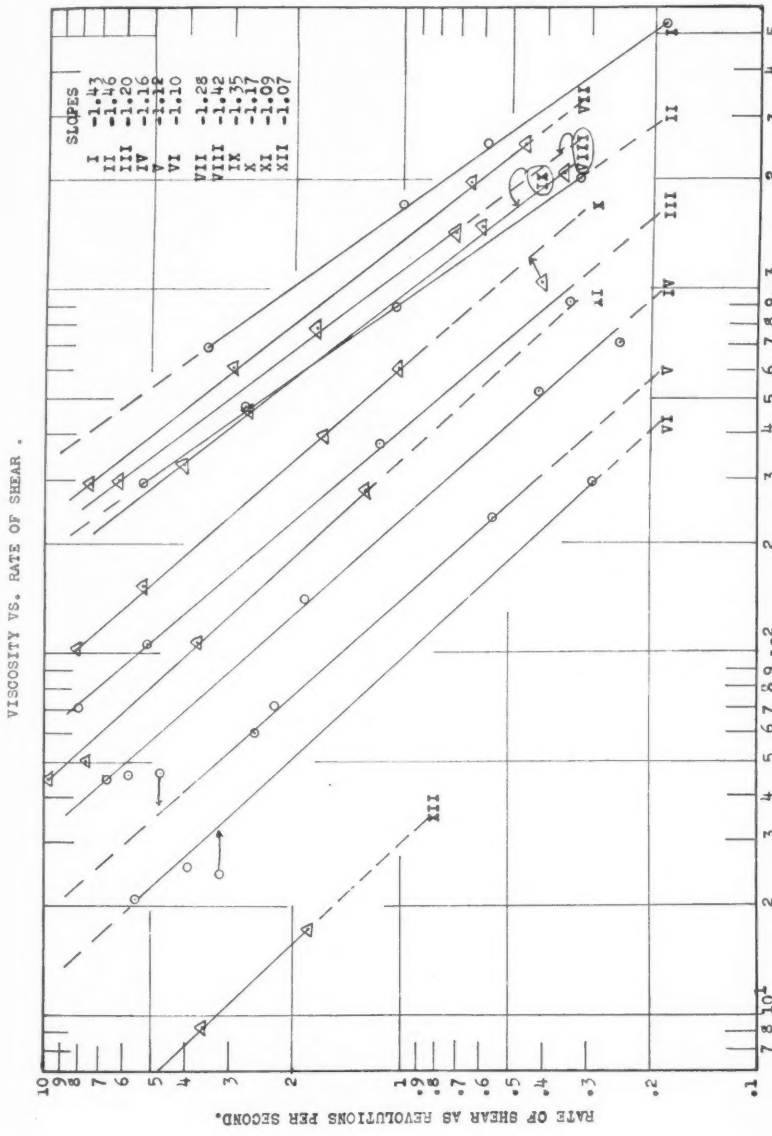
SLOPES
I -1.43
II -1.46
III -1.20
IV -1.16
V -1.12
VI -1.10
VII -1.25
VIII -1.42
IX -1.35
X -1.17
XI -1.09
XII -1.07
VISCOSITY VS. RATE OF SHEAR.
RATE OF SHEAR AS REVOLUTIONS PER SECOND.
VISCOSITY Z IN CENTIPOISES

FIG. 6.

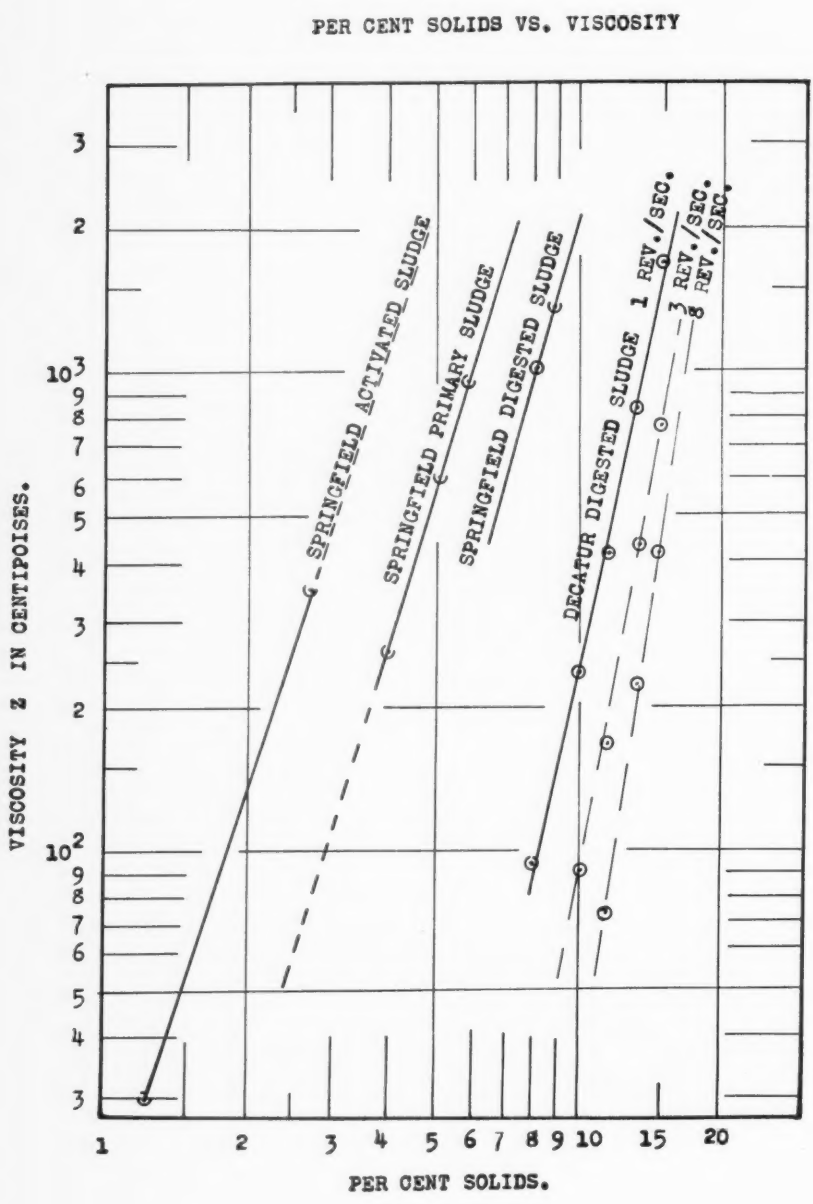
PER CENT SOLIDS VS. VISCOSITY
VISCOSITY Z IN CENTIPOISES.
PER CENT SOLIDS.
SPRINGFIELD ACTIVATED SLUDGE
SPRINGFIELD PRIMARY SLUDGE
SPRINGFIELD DIGESTED SLUDGE
DECATUR DIGESTED SLUDGE 1 REV./SEC.
3 REV./SEC.
8 REV./SEC.
3
2
10³
9
8
7
6
5
4
3
2
10²
9
8
7
6
5
4
3
1
2
3
4
5
6
7
8
9
10
15
20

FIG. 7.

Summary

A method for studying the viscous flow properties of sewage sludge is described, using a rotational viscometer and varying the shearing stress over a considerable range.

The "rate of shear-shearing stress" data show clearly the fluid-flow properties of thick sewage sludges. These properties plot into a curve closely resembling the pseudo-plastic shear-stress curve.

The normal effect of temperature is to increase the viscosity as the temperature is lowered and *vice versa;* however, elevated temperatures may cause an *increase* in viscosity due to gas bubble formation within the sludge, which overcomes the normal temperature effect.

The sludges have an interesting property of losing a considerable portion of their apparent viscosity or plastic resistance on agitation or stirring. This property must be carefully considered in sampling and handling sludges for viscosity determinations, and in the determination itself. This thixotropic property of sludges suggests certain practical applications in the pumping of thick sludges and in increased convection velocities past submerged heating coils in heated digestion tanks.

The apparent viscosities of primary (raw), Imhoff and separately digested sludges, and activated sludges have been determined and compared from various points of view. The apparent viscosity is made up of a true viscosity which is small (25 to 150) plus a plastic or pseudo-plastic resistance which may be 10 to 1,000 times the true viscosity. This resistance is probably due to a *larger* extent to the organic lyophilic particles and their water-binding properties, to a *lesser* extent to the inorganic lyophobic material, and to a *gel-like formation* which forms on quiescent standing but which is broken up by agitation or stirring.

The apparent viscosities when plotted against the rate of shear or against the per cent solids produce in each case straight lines, on logarithmic coordinates, which are almost parallel, the former having a slope of -1.1 to -1.4 and the slope of the latter varying from $+0.22$ to $+0.33$, if compared on the same ordinates. These plottings indicate a surprising consistency in the data obtained by rotational viscometers on a material as heterogeneous as sewage sludges. A greater knowledge of the material and more experience in the technic of the determination should greatly improve the accuracy of the data and perhaps make the above mentioned lines truly parallel.

Discussion

In view of the preceding data showing the variation of viscosity with the rate of flow and the loss of plastic resistance due to stirring, it is not surprising that the A. S. C. E. Committee [10] concluded "It is evident from the tests made by the committee and from attempts made to derive coefficients of friction and of viscosity that the laws of viscous flow are not applicable." The following friction losses, using the Reynold's-

Stanton approach as suggested by Clifford,[11, 12] have been calculated using the information in Fig. 9 of the Committee's report and assuming the viscosities recommended by Clifford for sludges of 90 and 88 per cent moisture, and estimating a viscosity of 200 centipoises for the sludge of 86 per cent moisture.

COMPARISON OF HEAD LOSS IN 8 INCH PIPE AT CALUMET WORKS

Velocity Ft./Sec.	Loss of Head per 100 Ft. of 8 Inch Pipe					
	Sludge Moisture 90 Per Cent		Sludge Moisture 88 Per Cent		Sludge Moisture 86 Per Cent	
	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.
0.5	0.124	.23	.17	.45	.23	.75
1.0	.23	.30	.34	.57	.46	.85
2.0	.48	.47	.67	.70	.80	1.00
3.0	.74	.75	1.01	.95	1.38	1.20
4.0	1.08	1.20	1.35	1.35	1.85	1.55
Assumed Viscosity Z	100		142		200	

These calculated losses of heads show that the equation of flow

$$\frac{\Delta H_f D}{u^2 L} = \phi\left(\frac{Du\rho}{Z/1488}\right) = \frac{2f}{g}$$

gives very close checks with the observed losses at certain velocities, but that there is some error at lower or higher velocities. This difference is to be expected because of the pseudo-plastic properties of the sludge, by which the apparent viscosity varies with the rate of flow. These results give us a little more confidence in applying the uncorrected fluid flow laws, at least as an approximation. Let us therefore

IMHOFF SLUDGES FLOWING IN 8 INCH PIPES, CALUMET WORKS

Fig. 9, p. 1788, *Proc. A.S.C.E.*, Vol. 55

Velocities Observed Ft./Sec.	Viscosities in Centipoises (calculated)				
	Sludge Moisture Per Cent				
	94	90	88	86	
0.5	40	186	382	720	
1.0	42	127	241	373	Viscous flow region
2.0	5	98	148	211	
3.0	8	19	132	165	
4.0	6	17	25	170	
5.0	8	14	21	32	Turbulent flow region
6.0	9	13.5	17	25	
7.0	8	11	15	14	

calculate the apparent viscosities of the Calumet sludges using the observed data in the above equation and calculating for Z with the aid of the plotted Reynold's number-friction factor curves which may be found in most handbooks or text books on fluid flow.

These viscosities, calculated by the fluid flow equation, show a decrease with increasing velocities to the point of critical velocity above which point the viscosities suddenly drop approximately 80 per cent. These critical velocities check quite well with those calculated from the equation

$$V_{lc} = \frac{2100\mu}{D\rho} = \frac{2100}{7728}\left(\frac{Z}{D''S}\right) = 0.272\left(\frac{Z}{D''S}\right)$$

as follows;

LOWER CRITICAL VELOCITIES IN PIPES, FT./SEC.

Viscosity Z cp.	Pipe Sizes			
	4″	6″	8″	12″
1	.066	.044	.032	.022
10	.66	.44	.32	.22
100	6.6	4.4	3.2	2.2
1000	66	44	32	22

These data also show the interesting effect of pipe size and viscosity on the "lower critical velocity," V_{lc}.

Sufficient data are given in the A. S. C. E. committee report to calculate the viscosities of sludges flowing in numerous long pipe lines in Great Britain and America as follows:

CALCULATED VISCOSITIES OF SLUDGE IN LONG PIPE LINES

	Dia. D'' Inches	Vel. u Ft./Sec.	H 100 Ft.	Re $\frac{Dup}{u}$	Z cp.	Per Cent Moisture
Birmingham, Eng.	12	1.70	.529	520	310	90
Manchester, Eng.	10	2.79	1.717	500	443	89
Glasgow, Scotland	9	1.29	.475	475	195	88
Bradford, Eng.	8	3.12	.818	1,750	119	80(?)
Wolverhampton, Eng.	4	2.5	2.79	680	171	90
Pittsfield, Mass.	24	3.2	.20	40,000	15	—
Syracuse, N. Y.	5	2.5	.80	60,000	1.9	98+

At Bradford a *chemical sludge* is pumped by *air slugs at 50 to 60 lbs.* pressure. These two factors may explain the low viscosity for such a concentrated sludge. The other sludges, of from 88 to 90 per cent moisture, have viscosities of 120 to 450 centipoises, depending on the velocity, pipe diameter, method of pumping and other unknown factors. It is interesting that all the English sludges flow below the

critical velocity while the two American sludges flow in the turbulent region. The Pittsfield, Mass., sludge, flowing in a 24-inch pipe under turbulent flow at 3.2 ft. per sec., has a viscosity of the same order of magnitude as shown by the Imhoff sludge at the Calumet Works when flowing in 8-inch pipes and in the turbulent region.

These results are presented to show how well the theoretical results apply to actual problems but they are presented with a full knowledge that the equations representing the laws when applied to pseudo-plastic flows must have some correction which recognizes the "yield point" such as the Renier equation.[6] Further studies must be made of a rheological nature so that pseudo-plastic data may be used with some degree of precision in calculating flow characteristics, of sludges and muds. Such studies should be supplemented with more complete data on actual friction losses such as those presented by the A. S. C. E. committee. In all future studies great care must be taken to recognize the thixotropic property and not to re-pump or re-use the sample of sludge without recognizing the possible effect on its fluid properties.

The calculations of film coefficients of heat transfer check surprisingly well with actual engineering data. The effect of viscosity on the film coefficient is shown as follows by using the equation

$$h = 50 \sqrt{\frac{\Delta t^\circ}{Z}} .$$

(Very similar results were obtained by using the more complicated equation mentioned in the introduction.)

Viscosity Z	1	10	100	1000	2000	5000
Film coef. in B.t.u./sq. ft./hr./° F.	184	86	40	18	15	11

If the heating pipes lie in the quiescent sludge in the digestion tank the viscosities will be 5,000 or more because of the very low convection velocities, except in sludges undergoing such violent digestion that the stirring due to gasification decreases the viscosities. For comparison with the above calculations the following film coefficients have been determined experimentally, Queer [9] 10 to 27, Keefer [14] 10.7, Heilman [15] 10.2 and Walraven [16] 10.2 B.tu./sq. ft./hr./° F. These data would indicate an advantage in keeping the heating pipes in the supernatant liquor or the thin actively digesting sludges, and the advantage of artificial convection of the sludge past the heating coils.

Conclusions

1. A rotational viscometric method of studying the viscous properties of sewage sludge has been described.

2. The viscous properties of sewage sludge have been shown to be

[14] C. E. Keefer, *Water Works and Sewerage*, **80**, 81 (1933).
[15] Heilman, *Sewage Works J.*, **5**, 179 (1933).
[16] J. B. Walraven, *Eng. News Record*. **112**, 8 (1930).

pseudo-plastic, *i.e.* the apparent viscosity decreases as the rate of shear and the shearing stress increase.

3. The sludge is thixotropic, the pseudo-plastic resistance and therefore the apparent viscosity being greatly reduced by stirring or shaking.

4. The apparent viscosity when plotted against the rate of flow or the per cent solids produces a straight line on logarithmic coordinates.

5. Application of the laws of fluid flow to sewage sludge gives valuable information even though these laws are only an approximation when applied to pseudo-plastic flow. Further studies should be made to correct the equations of flow for the pseudo-plastic properties of sludge flow.

Acknowledgment.—The author wishes to acknowledge the valuable assistance and cooperation of Mr. Evert Schlie in much of the laboratory work and to the A. E. Staley Manufacturing Company for the Stormer Viscometer used in these studies.

STUDIES OF ACTIVATED SLUDGE OXIDATION AT INDIANAPOLIS *

By Don E. Bloodgood

Superintendent, Sewage Treatment Works, Indianapolis, Indiana

There has been a need for a determination that will tell how heavily an activated sludge is loaded and how much work it may be expected to do, so that it may not be quite so necessary to operate a plant by the smell, look and feel method. At Indianapolis, a procedure and device have been worked out which have given information that has been very helpful in directing the operation of the plant.

The original studies were made in a machine in which the air was jetted through the samples by raising and lowering a tube of water which moved the air in the desired direction. This was a very tedious task, as might be imagined, and it was not long before my assistant, Mr. D. O. Bender, had devised a machine which worked automatically from a vacuum pump. Later he built a machine that was motor-driven. This machine had six units and served the purpose for a number of months. It is needless to say that the information obtained with these early machines gave encouragement and data that helped in the design of the machine now in use. The preliminary work is a thing of the past and this paper is to deal largely with the present method of performing the test and the manner in which the results are used in the control of the operation of the activated sludge plant.

Description of the Machine

There are two fundamentals about the machine (Figs. 1*A* and 1*B*) that are of great importance to its proper functioning. The first is that it supplies to the sample the maximum amount of air that can be physically taken up by the sample and the second is the important fact that the proper equilibrium of oxygen and nitrogen is maintained in the machine at all times.

The part of the machine holding the sample is a one-liter glass cylinder which is capped at both ends with aluminum plates and fastened to a backing board (Fig. 1*A*). Set into the bottom plate of the cylinder is an aluminum cup that holds a one-inch circular porous disk. The air is forced through this disk by means of a diaphragm pump made from an ordinary automobile fuel pump, except that the diaphragm is replaced by one of rubber. Suction for the pump is through a baffled glass container holding caustic solution to remove the carbon dioxide produced by the sample. The inlet to the caustic chamber is connected to the top of the sample cylinder. Connected into this system is a supply of pure oxygen. The decrease in the volume of this supply is measured by water displacement in a burette. A thermom-

* Presented at the Tenth Annual Convention of the Central States Sewage Works Association, St. Paul, Minn., Oct. 22, 1937.

eter placed in the top of the cylinder indicates any change in temperature of the air being diffused through the sample.

In the discussion of this paper there are two terms which should be explained, so that when they are used in the paper their meaning will be clearly understood. The first is *sludge demand,* meaning the amount of oxygen, in p.p.m. per hour, that is used by a 0.50 per cent solids sludge, which has had its normal period of aeration since being

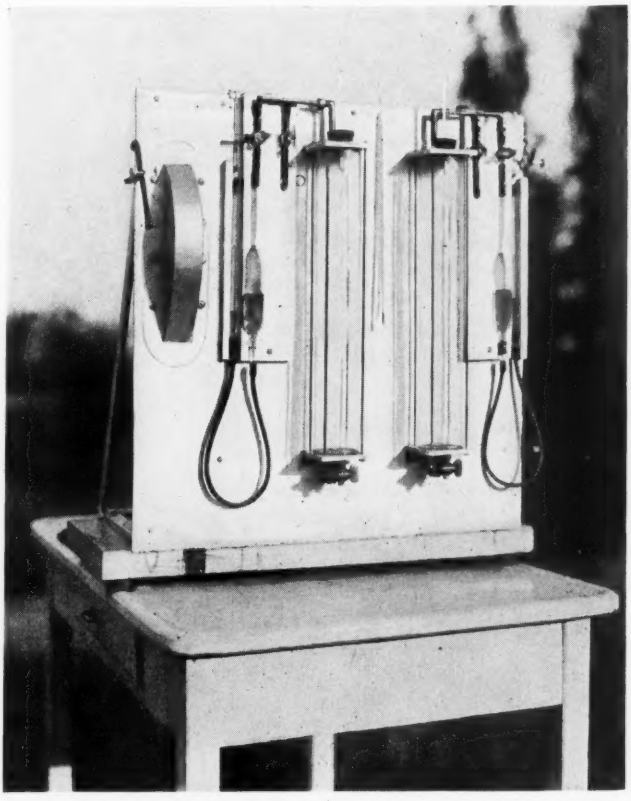

FIG. 1*A*.—Front view of Indianapolis machine for study of activated sludge oxidation.

mixed with sewage. The second is *sludge activity,* which is the rate of oxygen consumption, less the sludge demand, when synthetic sewage and sludge are combined to form a 0.50 per cent mixture. It is also expressed in p.p.m. per hour.

OBSERVATIONS FROM EARLY WORK

Some of the earliest work showed that each dilution of a sample of activated sludge had an oxygen demand of its own which was directly proportional to the solids content of that dilution. It was

learned further that the temperature at which a sample was aerated had a marked effect upon the rate of oxygen used. The data compiled upon this particular phase showed that the oxygen demand of a sludge was changed approximately 3 p.p.m. per hour for each change of one degree between the limits of 10° and 30° Centigrade. Other observations of the effect of temperature brought out the fact that activated sludge to which sewage was added would not show a normal activity if the sludge was first heated to 45° Centigrade.

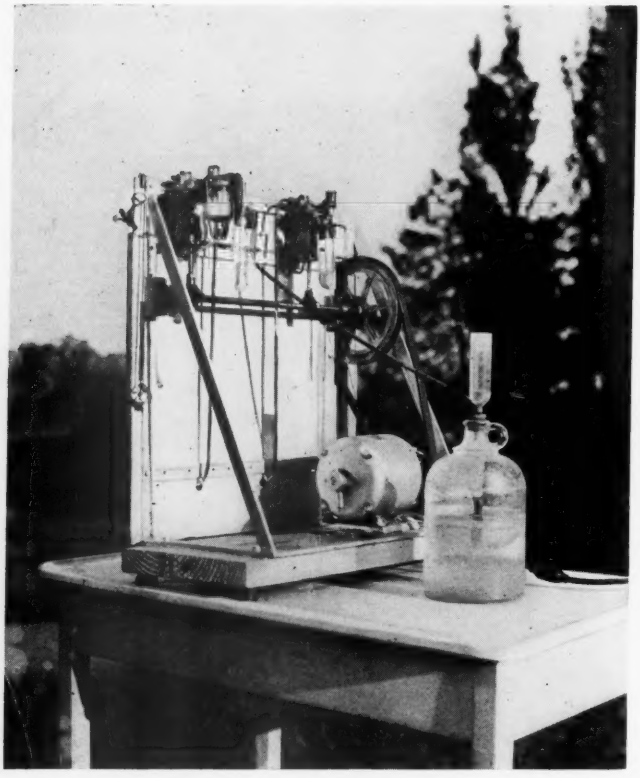

FIG. 1*B*.—Rear view of Indianapolis machine for study of activated sludge oxidation.

PROCEDURE IN MAKING A ROUTINE TEST

A sample containing activated sludge is taken and concentrated or diluted, as the case demands, to approximately 5000 p.p.m. or 0.50 per cent solids. The sludge is then put into the machine and kept under air until the exact concentration of solids has been determined. After this the sludge solids are adjusted to exactly 0.50 per cent and then the sludge is brought to room temperature. The machine is then closed and readings are taken on the quantity of oxygen used during each five-minute interval for a period of twenty minutes. The volume of

oxygen used is converted to weight and the result is the oxygen demand of the sludge. At the end of the twenty-minute period the machine is opened and a quantity of synthetic sewage, made of half peptone and half dextrose to produce a 5-day B.O.D. of 145 p.p.m., is added to the sample. After allowing exactly two minutes for mixing after adding the synthetic sewage, the machine is closed again and the amount of oxygen used in each five minutes of a 90-minute period is noted.

The concentration of solids in the sample tested is always adjusted to 0.50 per cent. This makes it possible to compare one test with any other test. The concentration of 0.50 per cent is used to magnify the readings and to shorten the necessary time to obtain a complete curve. The time elapsing between the taking of the sample and the starting of the test is of little consequence, if it does not exceed one hour and the oxygen demand of the sludge is not over 60. The adjustment of the sample to room temperature is quite important because slight changes in temperature will change the volume of air in the machine and thus affect the readings. It is also necessary to conduct the tests in a room free from draughts of varying temperatures. There may be some objection to the use of synthetic sewage but it does add uniformity to the test, so that it is possible to compare the behavior of one sludge with another. The so-called sludge demand, or the amount of oxygen required by the sludge alone, is a measure of the amount of load which that particular sludge is carrying within itself. In the past year the minimum demand of any sludge has been 10 and the maximum 85 p.p.m. Usually the lower the demand of the sludge the slower will be the rate of change of this demand. To interpret the behavior of a sludge after synthetic sewage is added to it, it is almost necessary to plot the results of the five-minute readings, less the sludge demand, against time. Curves of many shapes and types have been plotted and some are shown in Fig. 2. Sufficient information has been accumulated to prove that the shape of the curve indicates certain characteristics of a sludge. A curve which shows a high initial demand, which decreases soon after the run has started, is interpreted as a sludge which is very active and will do its initial purification in a short period of time. These curves vary from the one just described to the other limit, or sludge which purifies more slowly. These conclusions as to sludge activity have been confirmed by data on plant effluent quality and nitrification.

Since April, 1936, this test has been one of daily routine and is run at least every other day on each activated sludge plant unit. From October 1, 1936, to October 1, 1937, a total of 780 tests have been made. Each run was used to tell its individual story and not as data to be compiled and averaged to draw a final conclusion.

The results obtained with this test have been used to control the activated sludge plant units and as time has gone on it has been possible to increase the value of the test by more intelligent interpretation of the results.

In the routine determination, the sample of sludge to be tested is taken from the effluent end of an aerator. It can be readily seen that the oxygen demand of this material must be within certain limits, if it is to be a measure of the amount of load placed upon the mixed liquor solids. For instance; if the flow to a given aerator is materially increased the oxygen demand of the sludge will be materially increased at the end of the aerator. If for any reason the plant is suddenly charged with a high 5 day B.O.D. load, the demand of the sludge will also rise immediately. To keep a plant in good condition it has been

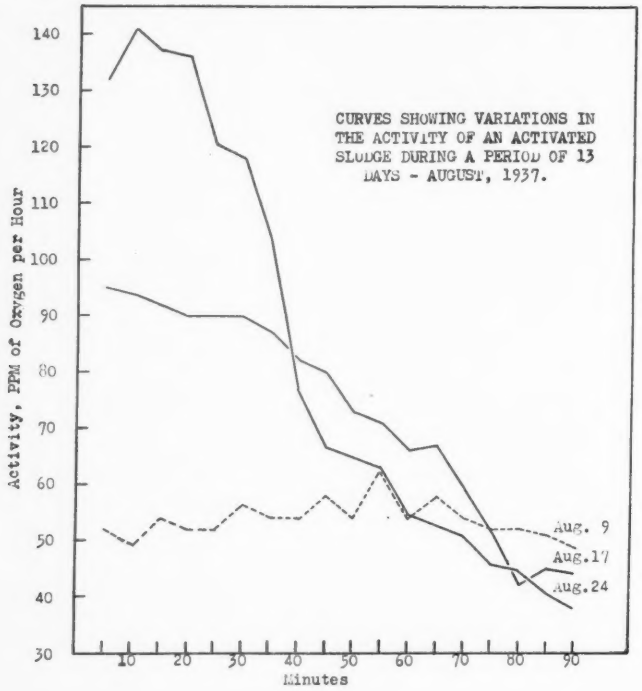

FIG. 2.

found necessary to keep the demand of the sludge between the limits of 25 and 50. A gradual increase from day to day indicates that the plant is being given more load than it can handle. If the increase be only slight then there is no cause for concern because it will be reduced over the week-end.

For purposes of interpretation the maximum activity is of note (see Fig. 3). It has been found that for the best operating results the maximum activity should range between 70 and 100 p.p.m. In most cases it has been found that when the activity gets higher than this, the sludge will not concentrate well, as measured by settling a 0.20 per cent solids mixed liquor in a 500 ml. cylinder for one hour. It is of

interest to note that the activity is highest during the time or immediately after a period of high sludge demand. It would seem that the activity might likely be a measure of organisms in the sludge, that the number of organisms depended upon the quantity of food present and that the number of organisms in the sludge affects the property of sludge settling.

To control the sludge demand and sludge activity, there are things that can be done; first, change the quantity of sewage flow, or the quantity of air used or the quantity of mixed liquor solids. These are not

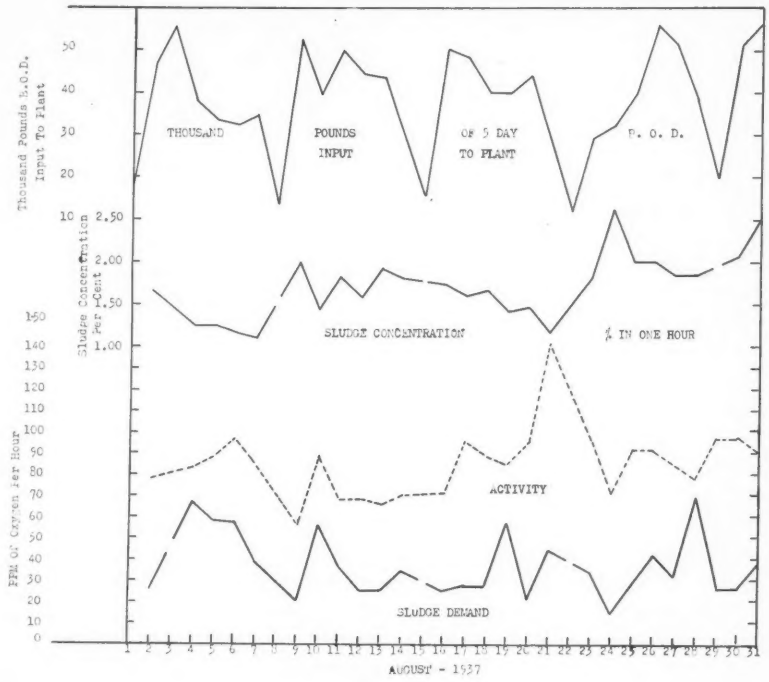
Thousand Pounds B.O.D. Input To Plant
Sludge Concentration Per Cent
PPM Of Oxygen Per Hour
THOUSAND POUNDS INPUT OF 5 DAY TO PLANT P. O. D.
SLUDGE CONCENTRATION
% IN ONE HOUR
ACTIVITY
SLUDGE DEMAND
AUGUST - 1937

FIG. 3.

new methods but the degree of change is quickly reflected in the results of the test under discussion.

During the past summer, the Indianapolis plant has been operated as five separate units. In many respects this has been very satisfactory, because not often are the sludges in the plants loaded equally and as a result it has been possible to divert flow to the units of lowest sludge demand, when some unit showed signs of trouble. The sludge demand and activity determinations have been found to be especially valuable when building new activated sludge in a unit, a procedure that will have to be carried out each spring, as long as the plant is operated on activated sludge in the summer time and on plain aeration in the winter. Treating the activated sludge as a strictly biologic mass, the

importance of maintaining just the right amount of food can be appreciated.

During the past year and one-half, it has been the policy to carry a daily graph of sewage flow, air flow, sludge index, mixed liquor solids, return sludge solids, suspended solids in the effluent, sludge demand and sludge activity on each separate activated sludge plant unit. The concentration of mixed liquor solids has been controlled so as to give oxygen demand and activity values found to give the best results. Changes in air flow may change the oxygen demand of the sludge, provided the quantity of air being used is not in excess of an amount that can be physically absorbed by the mixed liquors. It may happen that excessive amounts of air will cause the sludge to burn up, with a resulting loss of activity, so that when the next heavy load of sewage comes, there is no biologic life there to take care of it. This can be prevented by a reduction in the quantity of air, to prolong the consumption of the organic matter present and thus not greatly decrease the activity of the sludge.

One particular instance of the value of the determination was well demonstrated this summer. One afternoon a test on the sludge from one of the units showed a sludge demand of 80. This called for immediate action and the flow of sewage was diverted to another unit. A check on the meter disclosed that it was out of adjustment and that the aerator was being overloaded unwittingly. The unit recovered within twenty-four hours on the reduced flow and the other units taking the flow were not overloaded.

The sludge from the outlet end of an aerator and from the bottom of its settling tank should have a demand within five p.p.m. of each other. If there is a greater difference than this, it is likely that the sludge from the settling tank will be the higher and it will mean that the sludge is being held too long in the settling tank.

The tests have also been useful in determining the effects of certain trade wastes upon the activated sludge.

Conclusions

1. The oxygen demand of a sludge is a measure of the unoxidized matter it contains.

2. The sludge activity gives the rate at which a sludge can be expected to purify, and whether or not it can be expected to settle well.

3. By proper interpretation of results, changes in plant operation can be made to aid materially in the control of bulking activated sludge.

COMPARATIVE EFFECTS OF ACTIVATED CARBON AND LIME ON SLUDGE DIGESTION

By C. E. Keefer and Herman Kratz, Jr.

Bureau of Sewers, Baltimore, Md.

Numerous experiments have been conducted in the laboratory and the field to determine whether activated carbon will hasten sludge digestion. The laboratory investigations of Rudolfs and Trubnick [1] indicated that this material stimulated the digestion of sludge. On the other hand Walker [2] found that activated carbon proved of no benefit when sludge was digested at 28° and 45° C. At 20° C., however, he obtained somewhat better results. Plant scale tests have been made by Rogers [3] at Garden City, N. Y., and by Smith [4] at Newark, N. Y. Even if activated carbon should promote digestion, it is questionable whether this material would ever be extensively used unless it should be considerably superior to lime, which costs from about one-fourth to one-fifth as much. It was considered of interest to investigate the comparative effects of activated carbon and lime on sludge digestion. A series of experiments, therefore, were conducted on a laboratory scale with these two materials. This study indicated that both unseeded and seeded raw sludge digested much more rapidly when treated with lime than when activated carbon was used.

Experimental Procedure

A quantity of raw sludge was obtained from one of the large mechanically cleaned preliminary sedimentation tanks at the Baltimore sewage works. Although this material was in a comparatively fresh condition, it had begun to decompose as is apparent by the pH value (Table I), which was 5.9. The ripe sludge, used for seeding purposes,

Table I.—*Analyses of Sludges Used*

	Volatile Matter, Per Cent	Solids, Per Cent	pH
Raw sludge	80.4	4.66	5.9
Digested sludge	61.1	6.26	7.2
Raw and digested sludge *	73.7	5.30	6.0

* Two parts by weight of raw volatile solids to 1 part of digested volatile solids

was drawn from a large digester, which had a temperature between 85° and 100° F. The raw sludge was divided into eight parts, which were segregated into two groups, each containing four portions. To one group no seeding material was added, and to the other digested sludge was introduced in the ratio of two parts by weight of raw volatile solids to one part of digested volatile material. Each portion of sludge,

which weighed 20 lb., was put into a 5-gallon bottle, and incubated at 28° C. ± 1°.

The four bottles containing the unseeded material were treated in the following manner: No treatment was given the sludge, which served as a control, in one of the bottles; to the second bottle activated carbon, amounting to 8 per cent by weight of the volatile solids, was added; the third bottle also received this same amount of activated carbon together with sufficient lime from time to time to keep the pH value of the sludge up to 6.8 or 7.0, and the fourth bottle of sludge was treated with lime in order to maintain the above mentioned pH values; however, no activated carbon was used. The four bottles of seeded sludge were treated in the same way as the unseeded material. The gas generated by the sludges was measured periodically and analyzed. The sludges were analyzed at the end of the experiment as indicated in Table II.

TABLE II.—*Analyses of Sludge and Gas Production at End of Experiment*

	Treatment		Volatile Matter, Per Cent	Solids, Per Cent	pH	Gas Produced by Raw Volatile Solids	
	Lime, Grams	Activated Carbon, Grams				Total Gas, C.c. per Gram	Methane, C.c. per Gram
Raw sludge (unseeded)	None	None	74.3	3.40	6.2	100	36
	None	27.2†	75.7	3.73	5.3	34	3.3
	75	27.2†	57.6	3.32	7.7	617	426
	95	None	47.3	3.16	7.7	644	443
Raw sludge (seeded) *	None	None	63.4	3.51	7.7	594	388
	None	18.3†	65.3	3.80	7.5	521	334
	50	18.3†	60.2	4.03	7.8	700	482
	70	None	56.5	3.89	7.7	689	475

* Two parts by weight of raw volatile solids seeded with 1 part of digested volatile solids.
† 8 per cent of raw volatile solids present.

RESULTS

The extent to which the sludges digested has been judged by the gas production. Figures 1 to 4, inclusive, show the total gas and the methane given off by the different materials during a 100-day period.

Unseeded Raw Sludge.—The unseeded raw sludge that was treated with lime digested in about 60 days with the production of approximately 603 c.c. of gas per gram of volatile solids (Fig. 1). During this same time the sludge to which both lime and activated carbon were added had generated about 502 c.c. of gas or not quite 84 per cent of the gas yield from the sludge treated with lime alone. The gas production from the sludge that was treated with neither lime nor activated car-

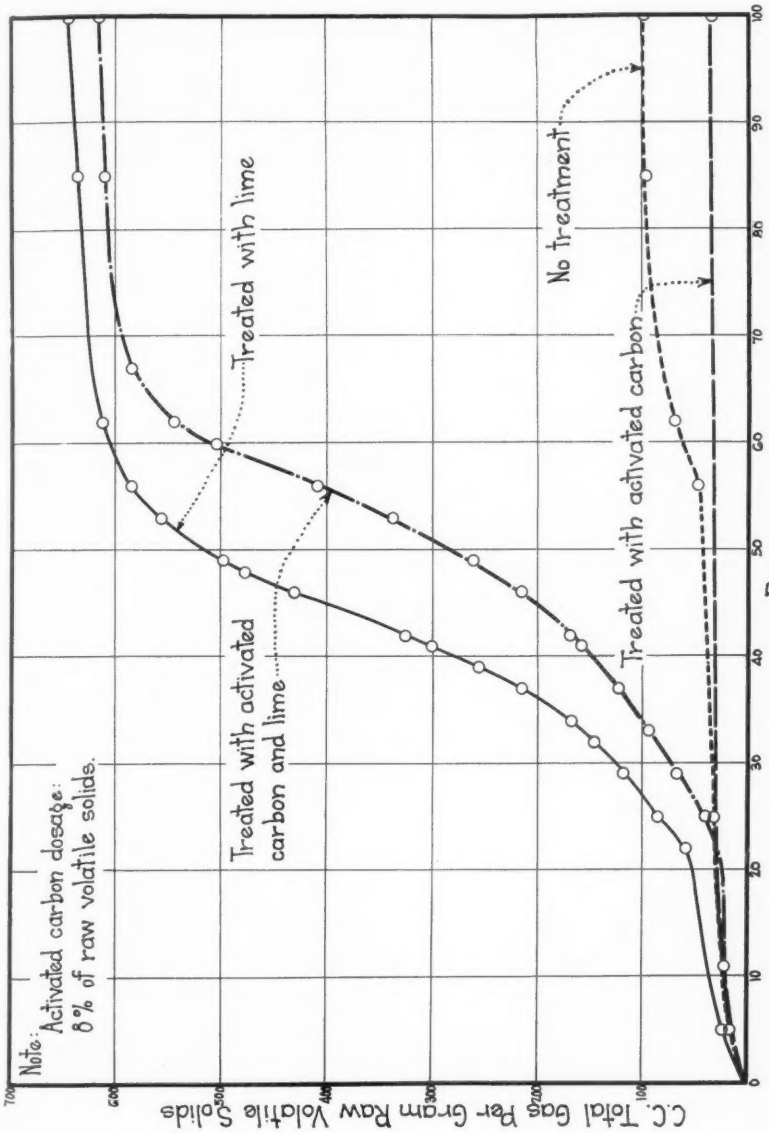

FIG. 1.—Total gas production from unseeded raw sludge treated with lime and activated carbon.

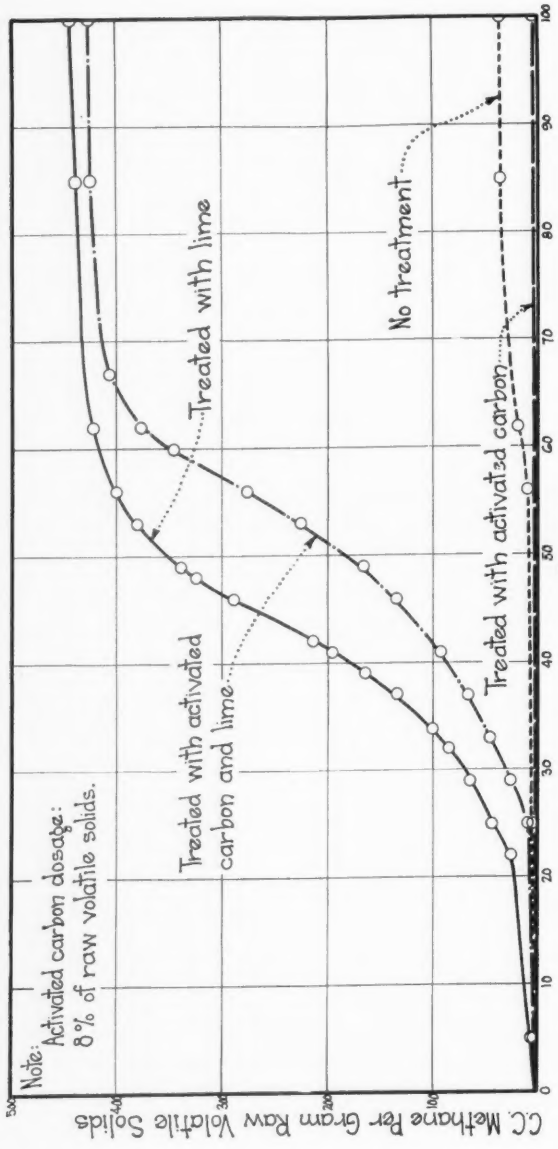

FIG. 2.—Methane production from unseeded raw sludge treated with lime and activated carbon.

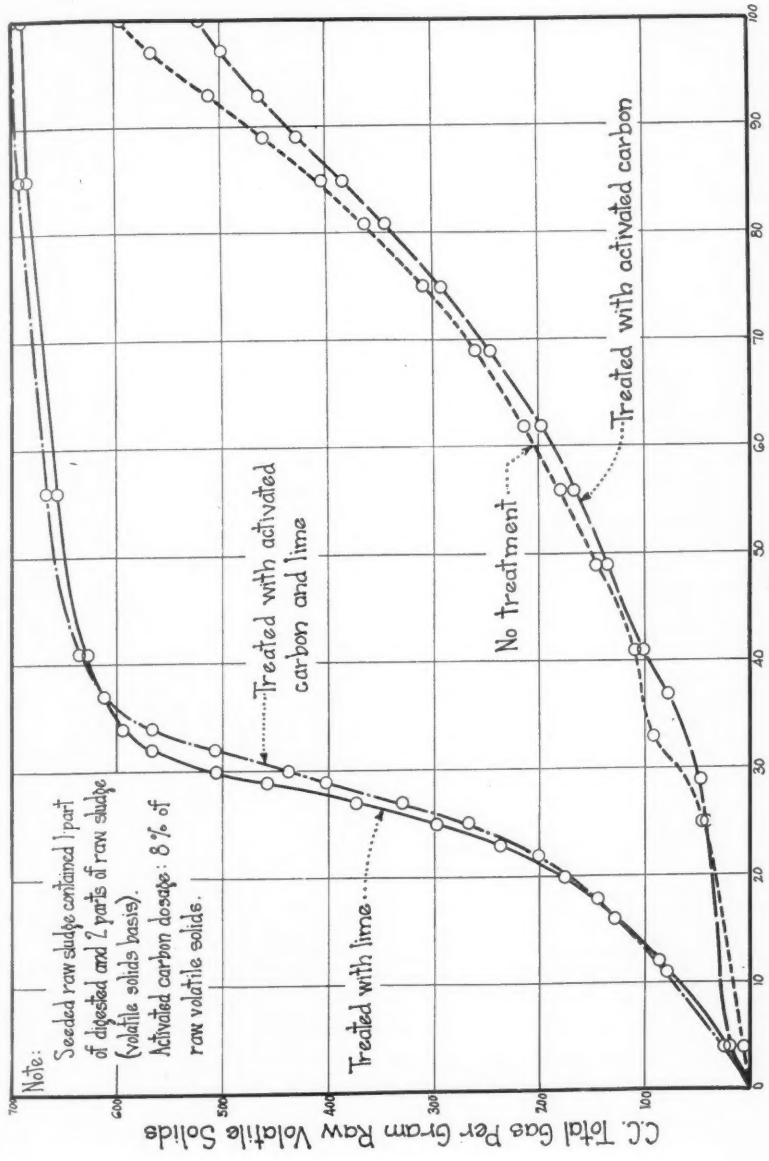

FIG. 3.—Total gas production from seeded raw sludge treated with lime and activated carbon.

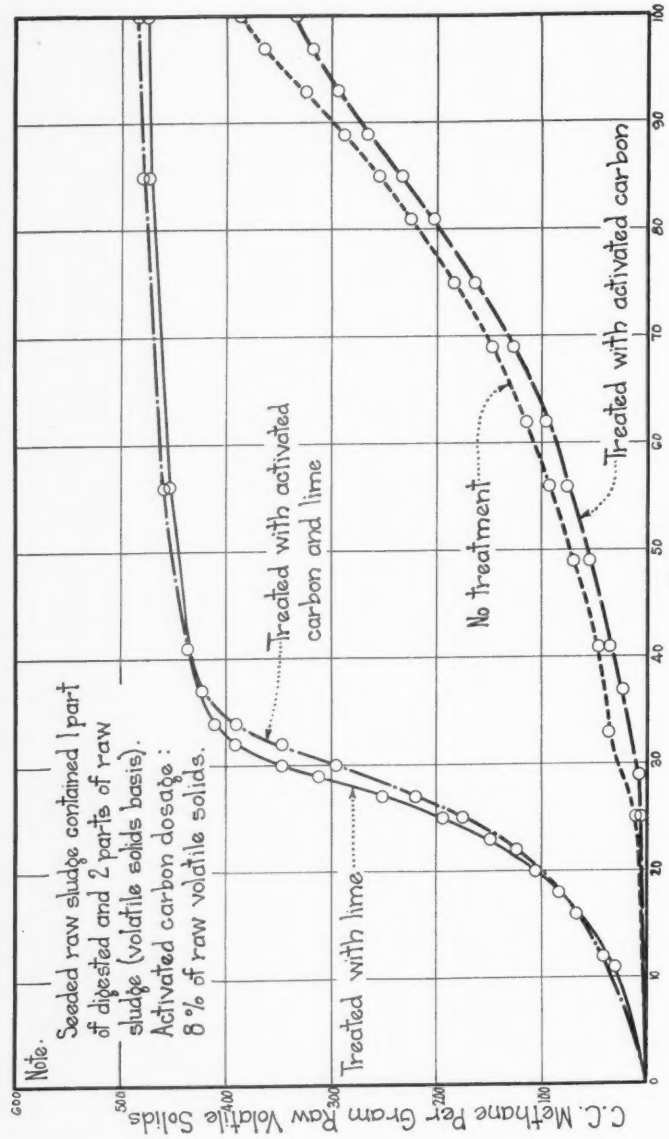

FIG. 4.—Methane production from seeded raw sludge treated with lime and activated carbon.

bon was naturally quite low at the end of both 60 and 100 days. The lowest gas production was from the sludge to which only activated carbon was added. At the end of 100 days 34 c.c. of gas per gram of volatile solids was generated.

Seeded Raw Sludge.—The seeded raw sludge treated with lime alone digested in about 40 days with the production of about 622 c.c. of gas per gram of raw volatile solids (Fig. 3). The sludge to which both lime and activated carbon were added digested in this same time with

TABLE III.—*Analyses of Sludge Treated with Activated Carbon*

Test No.	Raw Sludge			Digested Sludge			Mixture * (Untreated)			Mixture * (Treated with Activated Carbon)		
	Dry Solids, Per Cent	Volatile Solids, Dry Basis, Per Cent	pH	Dry Solids, Per Cent	Volatile Solids, Dry Basis, Per Cent	pH	Dry Solids, Per Cent	Volatile Solids, Dry Basis, Per Cent	pH	Dry Solids, Per Cent	Volatile Solids, Dry Basis, Per Cent	pH
Beginning of Experiment												
I	4.1	78.5	6.1	5.3	55.6	7.2	4.6	68.3	6.7	4.6	69.8	6.8
II	4.4	82.9	6.1	7.2	58.9	6.9	5.1	73.9	6.4	5.3	74.0	6.4
III	4.4	82.5	6.1	8.5	57.7	7.0	5.4	73.2	6.3	5.6	73.1	6.3
IV	4.0	81.8	5.9	8.4	54.9	7.2	4.9	71.5	6.2	5.2	72.1	6.3
V	4.7	82.0	5.9	8.7	56.0	7.0	5.7	71.4	6.2	5.9	72.3	—
End of Experiment												
I							2.7	53.9	7.3	2.8	56.7	7.3
II							3.1	57.7	7.6	3.3	59.5	7.6
III							3.4	57.7	7.7	3.6	58.9	7.5
IV							3.0	55.8	7.6	3.2	57.6	7.6
V							3.4	55.6	7.7	3.7	58.5	7.5

* Two parts by weight of raw volatile solids to 1 part of digested volatile solids.

the formation of slightly more gas. Digestion was very slow in the bottle receiving neither lime nor activated carbon. At the end of 40 days a little over 100 c.c. of gas per gram of raw volatile solids was given off. The sludge treated only with activated carbon digested the slowest, yielding slightly less than 100 c.c. of gas per gram of raw volatile solids.

Additional Tests Using Activated Carbon Alone.—A study of the above-mentioned experiments indicated that activated carbon retarded the digestion of both seeded and unseeded raw sludge. As these results are at variance with previous investigations conducted at Baltimore,[5] it was considered advisable to make a more extensive study of the problem. Raw sludge was obtained at the Baltimore sewage works, and was seeded by adding one part by weight of digested solids to two

parts of raw material on the dry volatile solids basis. This mixture was divided into two parts. To one part activated carbon was added in an amount equal to 8 per cent of the raw volatile solids present. No treatment was given the other portion. Five samples of raw sludge were collected on different days, and were treated by the method indicated above. Each portion was put into a 5-gallon bottle and incubated at 28° C. for a period of 160 days. The analyses of the sludges at the beginning of the tests are given in Table III. The volume of gas pro-

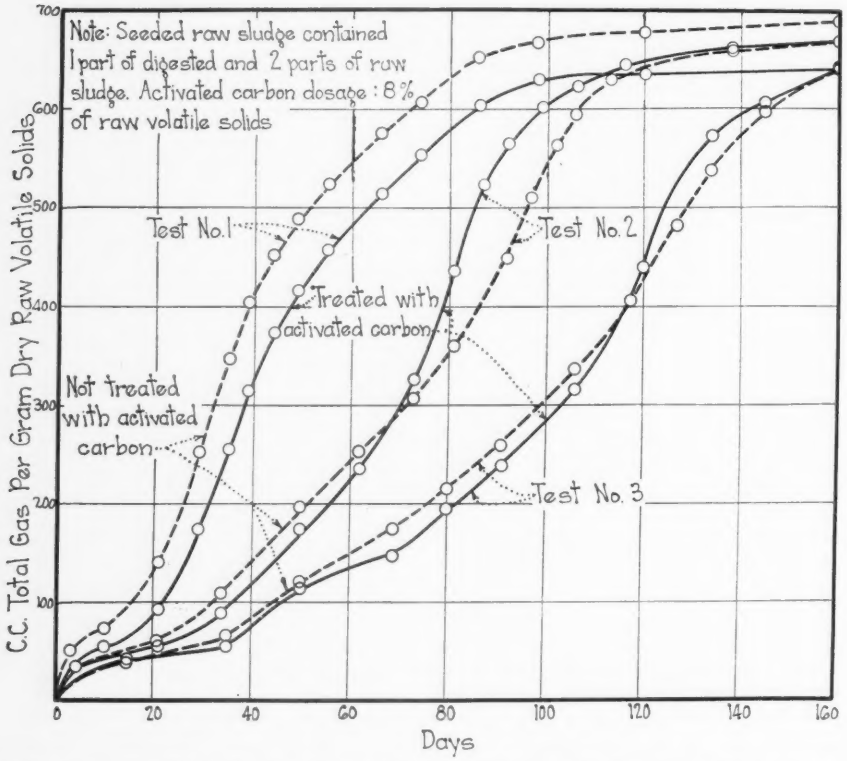

FIG. 5.—Gas produced from seeded raw sludge treated with activated carbon. Tests 1, 2 and 3.

duced was measured periodically and used as an index of digestion. The results are shown in Figs. 5 and 6.

Tests 1, 3 and 5 indicated that activated carbon retarded digestion. The untreated sludge used in Test 2 digested more rapidly than the treated material up until the sixty-eighth day of the tests. From then on the untreated material digested more slowly. Somewhat similar results were observed during Test 3. The analyses of the untreated digested sludges at the end of the digestion period and those treated with activated carbon are given in Table III. In every instance the untreated material contained slightly less solids and volatile matter.

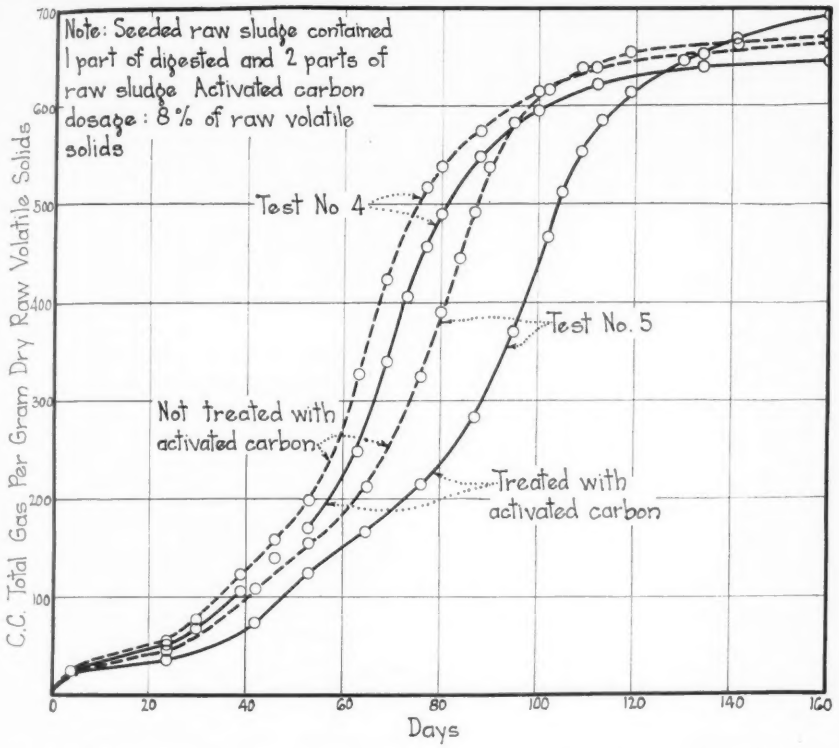

FIG. 6.—Gas produced from seeded raw sludge treated with activated carbon. Tests 4 and 5.

SUMMARY

The following summarizes the relative merits of activated carbon and lime as an aid in digesting both unseeded and seeded raw sludges. These conclusions apply to Baltimore conditions, and should be regarded as tentative until they are confirmed by more extensive experiments:

1. Lime was more effective than activated carbon in increasing the speed of digestion.

2. In the case of the unseeded raw sludge activated carbon and lime did not give as good results as the lime alone. These two methods of treatment yielded about the same results when seeded raw sludge was digested.

3. Somewhat conflicting results have been obtained when seeded raw sludge was digested with and without the addition of activated carbon. Previous tests,[5] which were made in duplicate under carefully controlled laboratory conditions, indicated that activated carbon hastened digestion. Six tests were made during the experiments described in this article. In four of these the untreated sludge digested more rapidly than the material treated with activated carbon. In the other two

tests activated carbon gave better results during the latter portion of the digestion period.

The Baltimore sewage works is under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer, with G. K. Armeling, superintendent, J. W. Bushman, junior chemist, assisted in the laboratory work.

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STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS*

IV. PRELIMINARY NOTES ON THE CLARIFYING ORGANISMS IN ACTIVATED SLUDGE

By H. Heukelekian and H. B. Schulhoff

Associate and Research Assistant, Div. Water and Sewage Research, New Brunswick, N. J.

The role played by bacteria in the clarification of sewage is being better understood. Butterfield (1) has isolated an organism which, when inoculated into sterile sewage or synthetic medium, produces the characteristic activated sludge floc and causes the removal of turbidity and oxygen consuming materials. Dienert (2) has made observations on the bacteria that clarify sewage by fixing themselves on submerged surfaces, such as pieces of glass, etc. Dienert (3) later observed that clarifying bacteria are different from oxidizing bacteria. In the present paper it will be shown that a number of organisms can be isolated from activated sludge or sewage which, when inoculated into sterile sewage, bring about clarification of the sewage. A preliminary attempt will also be made to show how the organic carbon of the sewage is transformed during the process of clarification by these organisms.

Method

Several pure cultures of clarifying organisms were obtained from activated sludge and sewage. The physiological and morphological characteristics of these organisms were determined but are not considered significant for the purpose of this paper. These cultures were inoculated into cotton strained sterile sewage and left either under quiescent conditions or aerated, with due precaution to eliminate contamination. Turbidity and oxygen consumed values of the supernatant after one hour's sedimentation were determined.

The experiments dealing with the carbon transformation were conducted essentially in the same way. Organic carbon was determined by the Mills (5) method on the whole mixture, settled sewage and the Seitz filtrate.

Results

Pure cultures of clarifying organisms isolated from different sources were inoculated into sterile sewage and incubated under quiescent conditions for a period of 20 days. At intervals samples were withdrawn and turbidity and oxygen consumed values of the supernatant after one hour's sedimentation were determined. Results on some of the cultures are given in Table I. Considerable clarification of the

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

TABLE I.—*Effect of Pure Cultures on the Clarification of Sewage Under Quiescent Conditions*

Culture Number	Turbidity, P.p.m.*				Oxygen Consumed, P.p.m.*			
	Days				Days			
	0	4	11	20	0	4	11	20
2	208	160	64	74	89.5	86.7	67	63.0
W	208	194	80	84	89.5	89.3	68.5	67.5
4 D	208	90	66	64	89.5	79.5	68.0	65.5
Y	208	158	106	90	89.5	92.7	77.5	73.0
6 B	208	170	84	70	89.5	87.0	68.5	61.5
Z–1	208	176	94	90	89.5	93.2	76.0	70.5

* Of the supernatant after 1 hr. sedimentation.

sewage was obtained as measured by the turbidity remaining after different periods of incubation. The rapidity with which different cultures clarified sewage varied. Culture 4 D gave the most rapid clari-

TABLE II.—*Effect of Pure Cultures on Clarification of Sewage by Aeration*

	Aeration Hrs.	Turbidity * P.p.m.	Oxygen Consumed * P.p.m.
Raw sewage	0	236	66
" "	4	220	68
" "	42	66	49.5
Sterile sewage	0	236	68
" "	24	212	74
" "	48	218	69
Sterile sewage seeded with X	0	236	68
	24	158	69.5
	48	90	61.0
Sterile sewage seeded with Z–1	0	236	68
	24	106	73
	48	42	61.0
Sterile sewage seeded with culture 5	0	236	68
	24	134	69.5
	48	106	68.5
Sterile sewage seeded with 6 A	0	236	68
	24	190	70.5
	48	74	58.5
Sterile sewage seeded with 6 B	0	236	68
	24	120	67
	48	94	62.5

* Of the supernatant after 1 hr. sedimentation.

fication in 4 days while the other cultures gave the maximum clarification only after 11 days of incubation. The removal of turbidity thereafter was small, if any. The removal of oxygen consuming materials by these cultures was not as striking as the removal of turbidity. Maximum removal of oxygen consuming materials took place after 11 days of incubation, with little if any further removal thereafter.

In the next experiment cultures were inoculated into sterile sewage and aerated. The turbidity and oxygen consumed values of a series of cultures are given in Table II. The organisms normally present in the raw sewage clarified the sewage materially within 42 hours. Oxygen consuming materials were removed only slightly. Sterile sewage on aeration gave little if any removal of turbidity. Inoculation of

TABLE III.—*Organic Carbon in Before and After Sedimentation and in Seitz Filtrate*

Time	Inoculation	Parts per Million			
		Turbidity	Not Settled	Settled	Seitz Filtrate
0	Act. sl.*	260	42.1	41.5	24.2
18 hrs.	" "	34	37.0	18.0	11.9
0	4 D†	234	44.0	39.8	20.3
3 days	"	106	33.2	23.0	14.6
6 days	"	76	29.0	21.8	12.8
0 days	Zoogloea†	110	23.2	18.9	10.6
2 days	"	50	19.0	11.2	10.9
3 days	"	50	17.9	11.4	13.1
5 days	"	60	15.1	12.9	8.7

* /cc. of sludge to 3 liters sewage aerated.

† Under quiescent conditions.

sewage with various organisms resulted in considerable removals of turbidity. In one instance, Z–1, the removal of turbidity was in excess of that obtained by the raw sewage itself in 48 hours. With several other cultures the turbidity values approached that of the raw sewage in 48 hours. Once again the removal of oxygen consuming materials was not material, neither in the raw sewage nor in the sterile sewage inoculated with the cultures.

The carbon in the different fractions of sewage which were prepared by the aeration of sterile sewage in the presence of a small quantity of activated sludge and of pure cultures of clarifying organisms, is given in Table III. The difference between the organic carbon value of the settled sewage and that of the non-settled sewage may be regarded as the amount of carbon present in the sludge. By subtracting the carbon values present originally in the sludge from those obtained after aeration, the values for the sludge formed are obtained. The carbon

in the settled sewage is split into material finely dispersed and in solution by the difference between the Seitz filtered and settled values. The loss of material from suspension and solution during aeration is obtained by subtracting the value after aeration from the corresponding original values. The results of such calculations derived from the above experiment are given in Table IV. There was a loss of 11.2

TABLE IV.—*Distribution of Organic Carbon in Different Fractions*

Time	Inoc.	Sludge P.p.m.	Fine Dispersion P.p.m.	Solution P.p.m.	Increase or Decrease Over Original				
					Sludge P.p.m.	Fine Dispersion P.p.m.	Solution P.p.m.	Loss by Oxidation P.p.m.	C Lost Recovered in Sl.
									%
0	Act. sl.	.6	17.3	24.2	—	—	—	—	—
18 hrs.	" "	19.0	6.1	11.9	+18.4	−11.2	−12.3	5.1	78
0	4 D	4.2	19.5	20.3	—	—	—	—	—
3 days	"	10.2	8.4	14.6	+6.0	−11.1	−5.7	10.8	36
6 days	"	7.2	9.0	12.8	+3.0	−10.5	−7.5	15.0	16.5
0	Zooglea	4.3	8.3	10.6	—	—	—	—	—
2 days	"	7.8	.3	10.9	+3.5	−8.0	+ .3	4.2	45
3 days	"	6.5	0	13.1	+2.2	−8.3	+2.5	3.6	39
5 days	"	2.2	4.2	8.7	−1.3	−4.1	−1.9	7.3	—

p.p.m. carbon of finely dispersed material and of 12.3 p.p.m. of soluble material or a total of 23.5 p.p.m. during 18 hours' aeration of the sterile sewage in the presence of a small amount of activated sludge. Of this amount, 18.4 p.p.m. was recovered in the sludge. The loss of 5.1 p.p.m. of carbon might be attributed to oxidation.

The cultures were incubated under quiescent conditions for longer periods. There was less increase of carbon in the sludge containing the two cultures than in the series inoculated with activated sludge. The carbon recovered in the sludge decreased with both cultures after the initial period. With the zooglea cultures the amount recovered in the sludge after five days was lower than that obtained initially, indicating a decomposition of the sludge. More carbon was lost by oxidation with the pure cultures than was lost in the series inoculated with activated sludge. The amount oxidized increased with longer periods of incubation. A lower percentage of the carbon lost was recovered in the sludge. A higher percentage of carbon lost was oxidized with the pure cultures than in the series inoculated with activated sludge.

The results presented are of a preliminary nature. Before definite conclusions can be drawn, the carbon in the sludge must be checked by actual analyses rather than by calculations. In addition, the carbon lost by oxidation in the form of CO_2 evolved must be determined. In

a subsequent paper it will be shown what fraction of the original carbon in the sewage is transferred to the sludge; whether the source of the sludge-forming carbon is primarily the finely dispersed material or the substances in solution; what fraction of the carbon is oxidized and how the amount of carbon oxidized and transformed into the sludge varies with different cultures of clarifying organisms isolated from the sludge, and how the individual cultures vary from the mixed cultures as present in the activated sludge. Similar studies with the nitrogen fraction will elucidate the nitrogen transformation during the formation of the sludge by pure or crude cultures.

Discussion

Results have been presented which show that a number of organisms isolated from activated sludge clarify sewage slowly under quiescent conditions. When these organisms are aerated in previously sterilized sewage the clarification is more rapid. Because of the small amount of inoculum introduced, the rate and magnitude of clarification, even with aeration, are not comparable to those obtained with activated sludge. It is of interest to note that the clarification obtained by the pure cultures did not exceed the clarification of the unsterilized sewage. This again might be attributed to the paucity of the inoculation or to the greater variety of clarifying organisms present in the sewage. The clarifying organisms in the activated sludge originate in the sewage in which the sludge is developed. It is further noteworthy that the clarification, as measured by turbidity removal, exceeded the oxygen consumed values. Since both these determinations were made on the supernatant liquor after sedimentation, it appears that clarification was accompanied by the transformation of the suspended matter into soluble form. This action might take place either before or after the suspended matter is taken out of the liquid phase and transferred into the sludge.

In order to obtain a better insight into the transformation of the finely suspended and soluble matter into the sludge and *vice versa,* carbon determinations were made on the sewage before and after settling, and also on the Seitz filtrate. The results indicated that when using activated sludge as a source of inoculum, a greater proportion of the carbon lost in a finely dispersed and soluble state is recovered as sludge than with the pure cultures. The pure cultures were primarily of the oxidizing type. Once the sludge is formed it does not remain static, but on further incubation breaks down and is oxidized. Thus, while the percentage of the carbon recovered from the sludge decreased, the percentage lost by oxidation increased. It therefore seems that clarification may be obtained either through oxidation or by flocculation mechanisms and that certain organisms bring about clarification primarily through oxidation while others accomplish it by flocculation. That oxidation proceeds at a maximum rate during the so-called clarification stage has been shown in a previous paper (4).

Summary

Several cultures of organisms isolated from sewage and activated sludge and inoculated into sterile sewage gave considerable clarification under quiescent conditions and also with aeration. The oxygen consumed values of the sewage inoculated with these organisms did not decrease so rapidly as the turbidity. Preliminary results are given which show that when sterile sewage, containing only finely dispersed and soluble material, is inoculated with a small amount of activated sludge a considerable portion of the original organic carbon is found in the sludge. With certain pure cultures of clarifying organisms the amount of the finely dispersed and soluble organic carbon transferred into the sludge phase is smaller than with the activated sludge inoculation. It is further shown that these organisms destroy the sludge formed, or originally present, with longer periods of incubation. A method is outlined which should prove of considerable value in determining the relative role played by flocculation and oxidation in the clarification of sewage by different cultures of organisms.

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STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS *

V. AMMONIA UPTAKE

By R. S. Ingols

Assistant, Division Water and Sewage Research, New Brunswick, N. J.

Ammonia is one of the important constituents of sewage which is in part removed from a purified effluent. It is well known that under certain conditions the aeration of sewage with activated sludge is capable of producing an effluent low in ammonia. With sufficient aeration the activated sludge converts most of the ammonia to nitrites and nitrates. However, the literature is not in general agreement as to the mechanism by which the ammonia is removed from the sewage liquor. There are two general views regarding this removal: (1) accomplished by physical means such as adsorption or base exchange; (2) removal brought about by biological agencies independently of these physical forces. Since ammonia is a simple substance, there seems little reason to suppose that a combination of biological and physical forces should be necessary, but this must be kept in mind as a possibility.

Base Exchange Studies

(A) Electrodialysis.—The study of base exchange in activated sludge can be advantageously carried out by electrodialysis, for this method provides a direct determination of the labile cations originally present and simultaneously prepares the sludge for the adsorption of cations following the electrodialysis. This method has been used previously by Setter and Henderson (5) for the study of the base exchange properties of activated sludge.

In order to study the cation, ammonia, on or within the sludge and not that in the original liquors, it was necessary to replace the sludge supernatant liquor with ammonia-free water. By centrifuging the sludge and discarding the supernatant, followed by re-suspending the sludge in ammonia-free water and centrifuging several times, the ammonia-containing liquor was displaced by ammonia-free water. The sludge was then suspended in the minimum amount of water necessary to permit it to flow and placed in the center cell of a Mattson soil electrodialysis cell (3) with parchment paper for the dialyzing membrane. A low current density was maintained (0.1 ampere at 220 volts) by keeping a steady flow of distilled, ammonia-free water through the anode and cathode compartments. The current was discontinued at the end of two hours, because it is known that the ammonium ion migrates rapidly through a membrane; all of the ions were shown to have migrated in 5 hours (5).

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In an effort to show re-adsorption of an ion removed by electrodialysis, ammonia was selected as the ion that could be studied most readily, and as possessing great significance in the activated sludge process. Iron was tried and discarded, because the high pH of the cathode diffusate had rendered the iron insoluble. The concentration of the ammonia in all of the studies was determined by Nesslerization of the liquor which had been filtered through paper to remove the fine sludge floc.

In studying re-adsorption of ammonia, an aliquot of the dialyzed sludge was mixed with a like portion of the cathode diffusate. The ammonia contents of the dialyzed sludge liquor, the cathode diffusate, and the supernatant of the mixture were determined. The quantities of a typical run were as follows:

	Mg. NH_3-N in 0.5 Gr. Sample
(1) Dialyzed sludge	0.12 mg.
(2) Cathode diffusate	0.47 mg.
(3) Mixture of (1) and (2) determined	0.59 mg.
Mixture of (1) and (2) calculated	0.59 mg.

From these figures it may be seen that re-adsorption of ammonia does not take place. Since the adsorption (base exchange) potential of ammonia is lower than that of each of the other cations normally present in sludge, Na, K, Ca, Mg, Al, and Fe, it is not surprising that ammonia in such a low concentration as 0.3 p.p.m. was not adsorbed.

Since the concentration of ammonia in sewage is generally between 10 and 50 p.p.m. NH_3–N, sludge was added to an ammonium chloride solution to give a final concentration of 20 p.p.m. of ammonia. A portion of the electrodialyzed sludge was left in contact with the ammonium chloride solution for 40 minutes and then the sludge was removed by filtering through paper (electrodialysis tends to disperse the sludge). The ammonia content of the liquor was lower after contact with the sludge. About 3 mg. of NH_3–N per gram of sludge was adsorbed. This quantity of ammonia, absorbed by a gram of the dialyzed sludge, was found to be nearly equivalent to the quantity of ammonia released by a gram of the original sludge to the cathodic diffusate. This is not well understood, for electrodialysis should remove all cations and adsorption of a single cation might conceivably equal the total quantity of cations removed.

B. Electrodialysis and NaCl Washing

Dried Sludge.—The results given in the first part of the study of ammonia adsorption were obtained with "wet" activated sludge. Theriault and McNamee (6), in a study of the base exchange of activated sludge, did most of their work upon dried sludge; an attempt was therefore made to repeat their work. A single sample of sludge was treated in several ways prior to contact with a solution of ammonium

chloride. One-half gram samples of material from each of the following methods of treatment were placed in a solution of 200 ml. containing 20 p.p.m. NH_3–N. The sludge samples were left in contact with the ammonium solution for 40 minutes, and then the sludge was filtered off and the ammonia determined by Nesslerization.

Method of Treatment Prior to Ammonia Contact	Final Conc. of NH_3-N in P.p.m.
(1) Act. sludge dried at 110° C. for 12 hours	20.0
(2) Act. sludge dried at 110° C. for 12 hours followed by treatment in a 4 per cent NaCl solution for 20 min.; the sludge filtered and the excess NaCl removed with NH_3-free water	18.5
(3) Dialyzed sludge dried	20.0
(4) Dialyzed sludge dried and treated as (2)	18.5
(5) Ash from activated sludge	20.0
(6) Ash from activated sludge treated as (2)	20.0
(7) Ash from dialyzed activated sludge	20.0
(8) Ash from dialyzed activated sludge treated as (2)	20.0

Only the dried sludge treated with NaCl gave any adsorption, namely 3 mg. of NH_3–N per gm. of dried sludge at 20.0 p.p.m. NH_3–N originally. The dialyzed sludge did not show adsorption after drying, contrary to the previous results with the wet dialyzed sludge. The dried activated sludge was similar to the wet activated sludge in that each had to be treated to show ammonia adsorption. The ash of the activated sludge, dialyzed or non-dialyzed, showed no base-exchange activity. These results would indicate that the organic fraction is essential for the base exchange phenomenon in activated sludge, and that the inorganic fraction plays a minor role. As dried activated sludge is not normal for the activated sludge sewage treatment process, no further work was done on dried sludge.

Wet Sludge.—A comparison was made of electrodialysis and sodium chloride washing as methods of preparing the sludge for study. In order to prepare the sludge for study with sodium chloride a sample of sludge containing approximately half a gram (50 ml. of a sludge of 10,000 p.p.m.) was centrifuged and the supernatant liquor was discarded. The sludge was then placed in 100 ml. of 4.0 per cent sodium chloride for 20 minutes. The excess salt was washed away with ammonia-free water by centrifuging and re-suspending the sludge three times. The sludge was finally added to a solution containing a known amount of ammonium chloride and the mixture diluted to 200 ml. with ammonia-free water. The sludge was left in contact for 40 minutes, with occasional stirring, filtered and the filtrate Nesslerized. A sample of the same sludge was electrodialyzed as previously described. Each of these methods of treatment gave 3.0 p.p.m. NH_3–N adsorption per gram of sludge at 20.0 p.p.m. NH_3–N as the original concentration. Thus, for ammonia adsorption study, either method of preparing the sludge is satisfactory, and will give comparable results.

C. Effect of Anions.—It is a well recognized fact that NaCl and Na_2SO_4 act differently toward certain colloids. Ferric chloride, ferric sulfate, and chlorinated copperas in optimum quantities (1) are known to be definitely different in their coagulation of sludges, although the iron is tri-valent in each case. Ammonium chloride was used in the adsorption tests thus far reported; and it was considered of interest to see if changing the anion would affect the adsorption of the ammonium ion (cation).

A number of runs were made using several concentrations of NH_4Cl and NH_4HCO_3, and in addition one concentration of $(NH_4)_2CO_3$ and $(NH_4)_2SO_4$. Sludges from the Madison, Morristown and Hillsdale activated sludge plants were used. Approximately ½ gram samples of sludge on a dry solids basis were prepared for each quantity of ammonia studied, by sodium chloride washing of the sludge, as previously described. The sludge was added to the ammonia solution and diluted to a final volume, giving an approximate concentration of sludge of 2,500 p.p.m. For each adsorption, forty minutes contact time between the sludge and ammonia solutions was allowed.

The results are shown in Table I. The individual figures show

Table I.—*Effect of Anions upon Adsorption of the Ammonium Ion*

Salt	Original Conc. for Each Sample	Madison				Hillsdale				Morristown		Ave. Adsorp P.p.m.
		Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		
		Final Conc.	P.p.m. Adsorp.	Final Conc.	P.p.m. Adsorp.	Final Conc.	P.p.m. Adsorp.	Final Conc.	P.p.m. Adsorp.	Final Conc.	P.p.m. Adsorp.	
NH_4Cl.....	10	10	0	9	1	9	1	10	0	8	2	0.8
"	20	18	2	18	2	20	0	16	4	14	6	2.8
"	40	36	4	36	4	40	0	32	8	32	8	4.8
NH_4HCO_3...	10	—	—	10	0	9	1	10	0	9	1	0.5
" ...	20	15	5	15	5	18	2	18	2	18	2	3.2
" ...	40	—	—	30	10	36	4	36	4	36	4	5.4
$(NH_4)_2SO_4$...	20	18	2	18	2	18	2	18	2	18	2	2.0
$(NH_4)_2CO_3$..	20	15	5	15	5	18	2	18	2	14	6	4.0

rather large variations in the amount of ammonium ion adsorbed from a given salt by different sludges, and a difference in the quantity of ammonia adsorbed from the same initial concentration of ammonia nitrogen in the various salts, by any one sludge. With one exception increasing the ammonia concentration caused an increase in ammonia adsorption. Six of the thirty-six samples tested failed to show any adsorption and four of these failures occurred with sludges in contact with only 10 p.p.m. NH_3–N. The averages of the quantity of ammonia adsorbed, shown in the last column, indicate that the anions affect the adsorption of the ammonia. At comparable concentrations of ammonia the sulfate ion permits the least amount of adsorption while the carbonate ion permits the largest amount of adsorption. The bicarbonate ion permits greater adsorption than the chloride ion. In spite of

the variations in the individual figures, these results show without any reasonable doubt the phenomenon of base exchange in activated sludge, when it has been properly prepared by sodium chloride washing or by electrodialysis.

Aeration Experiments with Ammonia and Activated Sludge

A. Effect of Sodium or Calcium Ions.—In these experiments a concentration of 2,000 p.p.m. sludge was used. In general 20 p.p.m. of NH_3–N was used as the initial concentration. In order to speed up cell metabolism and thus increase the ammonia utilization, glucose was added to a duplicate set of tubes in the first experiment. The increase in the rate of ammonia uptake was not noticed for two hours, so that in each subsequent experiment the sludge was aerated for 2 hours with 200 p.p.m. glucose before the addition of the ammonia and either sodium or calcium chloride. The ammonia determinations were made upon samples taken at half-hour intervals. The samples were filtered through paper and the ammonia determined by Nesslerization of the filtrate.

Experiments with a control and one concentration each of sodium or calcium chloride (Table II) showed no alteration in the rate of am-

Table II.—*Effect of Varying Concentrations of Sodium or Calcium Chloride Upon Ammonia Uptake of Activated Sludge (Expressed in P.p.m. NH_3-N Remaining)*

	Set 1			Set 2			Set 3				
Sludge No.	1	2	3	4	5	6	7	8	9	10	11
Time of Aeration in Min.	Con.	600 P.p.m. NaCl	200 P.p.m. $CaCl_2$	Con.	1000 P.p.m. $CaCl_2$	3000 P.p.m. $CaCl_2$	Con.	3000 P.p.m. $CaCl_2$	3000 P.p.m. NaCl	6000 P.p.m. NaCl	12,000 P.p.m. NaCl
0	20	20	20	20	20	20	20	20	20	20	20
30	18	18	18	15	15	16	15	15	15	18	20
60	15	15	15	11	13	16	11	14	14	17	20
90	10	11	10	7	9	13	7	9	10	16	20
120	8	8	8	6	8	12	6	8	8	15	20
150	6	6	6	—	—	—	3	7	7	14	20

monia uptake by the activated sludge, either with a 600 p.p.m. NaCl or 200 p.p.m. $CaCl_2$ concentration. No retardation in the rate of ammonia removal was found when the concentrations of calcium chloride were increased in steps up to 1,000 p.p.m. $CaCl_2$. When the concentration of calcium chloride was increased to 5,000 p.p.m. a definite retardation was noticed. Finally, a comparison was made between sodium and calcium chloride and several higher concentrations of sodium chloride.

A composite of part of the results is given in Table II. Equal concentrations (3,000 p.p.m.) of sodium and calcium chloride (Columns 8

and 9) gave equal retardations of ammonia uptake. The difference in the effect of the same concentration of calcium chloride (Columns 6 and 8) is probably due to the differences in the sludge samples. Small differences of this nature may be expected from one sample to another of biological material. It will be seen that 12,000 p.p.m. NaCl completely blocked the uptake of the ammonia by the sludge.

Since the high concentration of sodium chloride blocked the uptake of ammonia, the question arose whether the lower salt concentration of 1,000 to 2,000 p.p.m. NaCl might show a cumulative effect. The ammonia uptake from activated sludge-sewage mixtures over a 30 hr. period in the presence of 1,000 p.p.m. NaCl was studied. The batch process of adding sewage was used for both the control and the test to which was added salt at each new addition of sewage. The sewage was changed three times the first day and once on the second day. A concentration of 1,500 p.p.m. sludge was used.

A slightly increasing concentration of sodium chloride was obtained by adding one gram of salt per liter of mixture at each change of sewage the first day, and then a larger increase by adding 2.0 grams the second day. Determinations of the ammonia content of the raw sewages and the effluents of the first aeration periods of each day were made. There was less than 0.3 p.p.m. NH_3–N remaining from 15 p.p.m. NH_3–N the first day, after 4 hours' aeration, while the ammonia decreased to 0.3 p.p.m. NH_3–N the second day in the presence of 2 grams NaCl. Thus, there was no cumulative effect in 30 hours of aeration from low concentrations of sodium chloride.

These results show that the uptake of ammonia by activated sludge is possible in the presence of high concentrations of other cations. In Table II is shown some uptake of ammonia when the sodium ions have a concentration in milliequivalents 90 times that of the ammonium ions (last two figures in Column 10). To indicate a cumulative effect, it was shown that the ammonia concentration was less than 0.3 p.p.m. NH_3–N in the presence of 792 p.p.m. Na. Thus, the ammonia uptake took place as the number of sodium ions approached 700 times that of the ammonium ions (assuming 100 per cent ionization).

B. Effect of Glucose and Chloroform.—The following study was devised to obtain direct evidence regarding the gross biological factors involved in the uptake of ammonia by activated sludge. In the previous section, glucose, which is a readily available source of energy, was added to the sludge to increase the cellular metabolism, but no evidence was presented to justify this practice. Several antiseptics were added to an aerating mixture of sludge and ammonia, but many of them interfered with the Nesslerization of the ammonia. Chloroform, which is a partial antiseptic, was finally selected as the chemical which would permit study of the ammonia uptake of activated sludge while its biological activities were blocked.

In order to determine the possible effect of chloroform upon base exchange, various concentrations of ammonium salts were added to

sludge in the presence of chloroform. The chloroform was added to each sample of sludge, before immersing the sludge in sodium chloride, and it could still be detected by smell when the sludge was mixed with the ammonium solution. There was definite adsorption in the presence of chloroform, comparable with the figures shown for Madison sludge in Table I. The salt concentration of 40,000 p.p.m. used in preparing the sludge for the base-exchange study probably caused a kill of over 90 per cent of the organisms (7) but this experiment showed that the chloroform did not alter the surfaces of the sludge so as to prevent the operation of the base-exchange mechanism.

For the determination of the effect of glucose on the ammonia uptake, three tubes with 2,000 mg. suspended solids of sludge were aerated for 2 hours. One of the sludges was aerated as the control, while 200 mg. glucose had been added to the two other sludges at the beginning of the aeration. At the end of the aeration period, 20 ml. of chloroform was added to one of the sludges to which glucose had been added. After 10 minutes more aeration, ammonia solutions were added to each sludge so that a final concentration of 22 p.p.m. NH_3–N was obtained in each. A sample was drawn immediately; aeration continued and samples were drawn at half-hourly intervals.

The results of a typical run are shown in Table III. Two hours of

TABLE III.—*A Comparison of the Rate of Ammonia Uptake by Activated Sludge Under Varying Treatment (Expressed in P.p.m.)*

Time	Aeration	Glucose plus Aeration	Glucose plus Aeration, Then Chloroform
0	22	22	22
½ hr.	19	19	22
1	18	17	22
1½	15	11	22
2	13	8	22

aeration with glucose increased the rate of ammonia uptake, but blocking the biological activity of sludge with a partial antiseptic prevented the ammonia uptake by the sludge. It should be noted that the chloroform was added to a sludge to which glucose had been added.

DISCUSSION

These experiments conducted with activated sludge to demonstrate the physical properties of adsorption of the sludge floc, showed that a small amount of ammonia could be obtained from the sludge by electrodialysis, and that the electrodialyzed sludge was then able to adsorb ammonia. The use of electrodialysis is a well recognized method of removing ions from colloids and is extensively used in studies of base exchange in soils. The adsorption of ammonia by the sludge that had been electrodialyzed may be considered as an indication of base exchange.

This conclusion was independently checked by washing the sludge in a concentrated solution of sodium chloride as a method of preparation. The variations in the amount of a substrate adsorbed in the presence of several different anions is a well recognized phenomenon in the study of widely used adsorbents such as carbon or bentonite. The variations in the amount of ammonia adsorbed by the sludge from ammonium sulfate, chloride, bicarbonate, and carbonate is another indication of the adsorptive property that may be induced in the sludge. The amount of adsorption varied inversely with the solubility of the various salts. This is a rather well accepted theory of behavior in colloid chemistry.

The changes which take place in activated sludge upon drying are quite evident, but nevertheless dry material has been used in the study of base exchange. As with the wet activated sludge, the dried sludge must be treated to show any physical adsorption of ammonia. A sample of electrodialyzed sludge, which showed ammonia adsorption before the sludge was dried, failed to show any ammonia adsorption after drying. This again indicates the marked changes that take place in the surfaces of the sludge upon drying. The results of the sludge ash experiments will not be discussed at this time, for an extensive paper on this subject is to be published in the near future from this laboratory.

Can the adsorption of ammonia be explained by the biological processes in the sludge? A bacterial count made upon sludge before and after electrodialysis for one hour showed a 90 per cent kill. Zobell, Anderson, and Smith (7) showed a 90 per cent kill of sewage organisms in a 5 per cent salt concentration in half an hour. Drying of the sludge caused a complete cessation of the life for the period of the experiment (certain spore-forming bacteria from the sludge are probably in the spore form but are not active). Also, the adsorption of ammonia may be demonstrated in the presence of chloroform. These facts would indicate that the sludge samples studied had removed the ammonia from solution by the physical process of adsorption. But, can the results obtained by these methods be used in interpreting the processes that are active when the sludge is being aerated?

A study of the cation exchange potentials reveals that the ammonium ion is the least strongly retained by the zeolite of any of the ordinary ions, or it may be said that other ions will most readily be adsorbed by an ammonium zeolite. The results obtained showed that ammonia uptake by activated sludge could occur in a concentration of sodium ions 700 times that of the ammonium ions. This indicated that base exchange could not be operative in removal of the ammonia. Sewage in most places contains the sum of sodium, potassium and calcium ions in a concentration greater than that of the ammonium ion. Although their concentration may not be as high as the concentration of cations used in these experiments, it is felt that the concentration would be high enough to interfere with any base-exchange mechanism. It is a well known phenomenon that root hairs can exercise selective ad-

sorption and in the same manner, the removal of the ammonia in the presence of the sodium seemed to be selective. Heukelekian (2), in a recent article, arrived at the conclusion that the uptake of ammonia by activated sludge was not a physical phenomenon. However, 12,000 p.p.m. sodium chloride blocked ammonia uptake by the activated sludge. It was found that this concentration of salt caused a considerable dehydration of the sludge for it was noted that the sludge occupied a much lower volume on settling. It was considered likely, therefore, that this dehydration was an indication of a highly toxic condition induced by the salt. Therefore, glucose was added along with the ammonia and the effect of the 12,000 p.p.m. NaCl studied with both. The glucose removal was also blocked along with the ammonia but the utilization of the glucose by the control was very low amounting to only 20 mg. per hour.* Another sludge had a very high glucose utilization, 150 mg. per hour, so that any difference between the control and the salted sludge could be easily noticed. The salt reduced the glucose utilization to one-sixth of the normal figure while completely blocking the ammonia utilization.

Another indication that it was the high osmotic pressure of the salt and not the high cation concentration of the salt that blocked ammonia utilization is shown by the fact that equal concentrations of sodium chloride and calcium chloride caused equal retardation of ammonia uptake, although the calcium ion has only half the concentration of the sodium ion at equal salt concentrations.

Permeability of cell membranes is another important manifestation of cell life. The alteration of the permeability of root hairs has been widely studied by plant physiologists. It is known that the predominance of a monovalent cation, sodium, will increase the permeability of root hairs to the other ions and conversely the predominance of a divalent cation, calcium, will decrease the permeability. In order to demonstrate an increased permeability to ammonia the assumption must be made that permeability of the cells is the limiting factor in the rate of ammonia utilization (*i.e.,* the cells can use more ammonia than they do usually but their membranes prevent its uptake). It must be also remembered that if the permeability of a cell should be increased too much, there could be no retention of the essential ions within the cell, death of the cells will ensue, and there will be an apparent decrease in cell permeability. No increase in the rate of ammonia uptake in the presence of sodium over that of the control was demonstrated, and so it was concluded that permeability is not a limiting factor in ammonia uptake by organisms in the activated sludge. The decrease in the rate of ammonia uptake in the presence of calcium chloride occurred at concentrations of this salt which were too high to permit the conclusion that the effect noticed was one of altered cell permeability due to the divalent cation.

The experiments with sodium chloride and calcium chloride indicated that base exchange was not an operative mechanism in the uptake

* Glucose determinations were made with a standard blood-sugar technique (4).

of ammonia by activated sludge. However, it was realized that several positive experiments were necessary to indicate that it was a biological process. The role of glucose in the removal of ammonia was studied. The addition of the glucose to the activated sludge hastened the utilization of the ammonia. Glucose does not enter into a direct chemical combination with ammonia, but it is well known that glucose may be utilized along with ammonia in building protoplasm. Thus, the glucose is not likely to increase the ammonia uptake immediately if the glucose causes the utilization of ammonia for this purpose. An indication of this as a possible mechanism was obtained in the results of the first experiment with salts where glucose was added, where the last 25 per cent of the ammonia was entirely removed from solution by the sludge to which glucose had been added. Glucose as a readily available source of energy might simply stimulate all of the biological processes in which ammonia participated. Whatever the explanation the ammonia was removed from the liquor by the activated sludge more rapidly when the glucose was added. This is an important piece of evidence indicating the biological processes in the uptake of ammonia by activated sludge.

Chloroform does not interfere with the adsorption of ammonia by treated activated sludge. It does block biological activity when present in sufficient quantity. Chloroform should block the removal of ammonia from solution completely if the uptake of the ammonia by activated sludge is a purely biological process. This it does. This phase of the results agrees well with the established fact that antiseptics such as toluene and formalin prevent the clarification of sewage by activated sludge. The high correlation between the blockage of the ammonia and glucose removal in the presence of 12,000 p.p.m. NaCl is another indication of the biological nature of the uptake of ammonia by activated sludge.

Summary

Studies are reported on ammonia uptake by activated sludge in which an attempt has been made to evaluate the relative importance of physical or biological processes in the initial removal of the ammonia by the sludge. The sludges were prepared by electrodialysis and also by washing with sodium chloride. The effect of various anions upon the adsorption was studied. The adsorption of ammonia by properly treated activated sludge was demonstrated.

The uptake of ammonia by activated sludge was demonstrated in concentrations of other cations, either calcium or sodium, which were many times the concentration of the ammonium ion. This indicated that base-exchange was not a likely mechanism in the uptake of ammonia. The effects of glucose, which would alter biological activity and thus the rate of ammonia uptake, were shown. These experiments indicated the importance of biological assimilation of ammonia. The use of chloroform, which is a partial antiseptic, showed that no removal

of ammonia took place in the absence of biological activity. This indicates the complete dependence of the uptake of ammonia by activated sludge upon biological phenomena, without the help of so-called physical processes.

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Plant Operation

RECENT LABORATORIES FOR LARGE SEWAGE TREATMENT WORKS *

By E. Hurwitz

Principal Sanitary Chemist, Sanitary District of Chicago

Sewage treatment works have undergone a vast building program in recent years. There have been many new plants constructed which contain chemical and bacteriological laboratories. It is the purpose of this paper to discuss the features of the design and equipment of some of the larger laboratories that have been completed in the past two years or which are now in process of completion.

I have selected, as typical, the laboratories at Columbus, Cleveland, Minneapolis-St. Paul, Washington, Buffalo, Ward's Island and the Southwest Side of the Sanitary District of Chicago. Plans and specifications were furnished by those in charge of the design of these laboratories and grateful acknowledgment is made to them later for their cooperation.

Area Provided

Table I shows the total amount of space occupied by each of these laboratories and by their various subdivisions. The laboratories in-

Table I.—*Laboratories for Sewage Treatment Works*

Plant	Flow to Plant M.G.D.	Approximate Space Occupied, Sq. Ft.												
		General Lab.	Bact. Lab.	B.O.D. Room	Hood Room	Balance Room	Coal, Oil, Materials Testing	Research Lab.	Wash or Preparation Room	Dark Room	Store Room	Vault or Record Room	Total Space Occupied	Effective Space Occupied
Columbus	50	770				200		340			290		1110	1110
Cleveland-Easterly Plant	120	600	315	75	145				185				1810	1520
Minneapolis-St. Paul	134	485	345		275			300	315				1720	1720
Washington	130	735	395	45		150		415			50	170	1960	1740
Buffalo	150	1130	410			65			405		105	30	2145	2010
Ward's Island	180	1265	465	90				250		95	145		2310	2165
Chicago-Southwest Side	400	1580	430				380		140		180	35	2745	2530

Effective space includes all space except that occupied by vault or record and storerooms.

crease in size as the plants which they serve become larger. Thus Columbus, with a flow to the plant of only 50 m.g.d., has allotted 1110 sq. ft. to its laboratory, while at the other end of the table, the laboratory of the Southwest Side Plant at Chicago, which will treat 400 m.g.d., occupies some 2745 sq. ft. of floor space. It is an interesting

* Presented at the Tenth Annual Meeting of the Central States Sewage Works Association, St. Paul, Minn., Oct. 21, 1937.

coincidence that, except for the small plant at Columbus and the very large Southwest Side Plant, approximately 13 sq. ft. of effective area —by that I mean all space devoted to actual laboratory operations, which would exclude vault, storeroom, office space, etc.—has been allotted to the laboratory for each million gallons of sewage flow.

For the plants selected, apparently the size of laboratory is not dependent on whether partial or complete treatment is provided. Thus, Washington and Buffalo have only sedimentation plus chlorination, Minneapolis-St. Paul has sedimentation, occasional chemical treatment and magnetite filters, and Cleveland and Ward's Island have activated sludge treatment; but the relative space allotted does not increase appreciably for the last three plants, as shown in Table II. Control of

TABLE II.—*Relative Space, Partial or Complete Treatment*

Name	Type	M.G.D.	Sq. Ft. per M.G.D.
Columbus	A.S.	50	22.5
Cleveland	A.S.	120	12.7
Minn.-St. Paul	Chem. filters	134	12.8
Washington	Sed.-cl.	130	13.4
Buffalo	Sed -cl.	150	13.4
Ward's Island	A.S.	180	12.0
Chicago S. W. Side	A.S.	400	6.3

separate digestion, chlorination and application of chemicals requires laboratory work of considerable magnitude, warranting the provision of ample space.

It is apparent from Table I that nearly all persons responsible for the design of these laboratories are agreed that separate space should be provided for chemical and bacteriological analyses. The area allotted to each is of course dependent on the scope and extent of work contemplated. At Buffalo, where sterilization with chlorine will be an important function of the plant, bacteriological analyses will be of primary importance. As a consequence the combined space of the bacteriological laboratory proper and the preparation room, some 815 sq. ft., which is devoted chiefly to bacteriological work, is about 40 per cent of the total working space provided. At the Chicago Southwest Side Laboratory, where it is expected that only a moderate amount of bacteriological work will be done, only about 20 per cent of the total working space was provided for this work. On the other hand the area set aside for chemical analyses is large, but not out of proportion when consideration is given to the large numbers of chemical analyses of all kinds—industrial waste, routine plant analyses, fertilizer, coal, oil, construction materials, paints and varnish, and any number and kind of miscellaneous samples—which are made in this laboratory.

In general, the relative sizes of the chemical and bacteriological subdivisions of these laboratories are designed with due consideration for the volume of each type of work contemplated. However, it seems

that possibly the 395 sq. ft. allotted the bacteriological laboratory at Washington may be found too small to care for the large volume of bacterial analyses and bacterial investigations which might be necessary at a plant depending on plain sedimentation and chlorination for treatment.

Special Units

Constant Temperature Rooms.—Provision is made for separate B.O.D. rooms at Cleveland, Washington, and Ward's Island. These specially constructed constant-temperature rooms are a very desirable feature provided they are properly located with respect to the other equipment for B.O.D. determination and provided their usually excessive cost does not over-balance their usefulness. A large room of this type, with elaborate control equipment was built at the North Side Treatment Works and also the Main Laboratory of the Sanitary District of Chicago, but in the later Calumet and Southwest Side Laboratories, such rooms have been abandoned, and large electric refrigerators, adjusted for 20° C. temperature, have been used. Also at Columbus, Minneapolis-St. Paul and Buffalo, specially designed refrigerators were used, placed at a convenient location in the chemical laboratory. The Columbus unit is a combined incubator and sample cooler. The Chicago Southwest Side Laboratory is provided with two units. Both are built according to the specifications of the General Electric Co. and are guaranteed by G. E. to maintain a temperature of 20° C. $\pm$ 1° C. The larger unit has a capacity of 970 B.O.D. bottles. The smaller or bacteriological unit has a capacity of some 750 B.O.D. bottles.

Fume Hoods.—Separate hood rooms are provided at Cleveland and Minneapolis-St. Paul. Hoods in the other laboratories are located in the general laboratory. In all but the Southwest Side Laboratory a part of the hood is used to house the Kjeldahl digestion apparatus.

Balance Rooms.—Rooms for balance work were built at Cleveland, Washington and Buffalo and special research laboratories were provided for Columbus, Minneapolis, Washington and Ward's Island. Ward's Island has also provided a dark room presumably for photographic work in connection with bacteriological research.

Storage Space.—Ample storage space, while it need not be provided on the laboratory floor, is requisite to a properly balanced laboratory. Storage space large enough to accommodate the day-to-day needs of the laboratory has been provided on the laboratory floor at Washington, Buffalo, Ward's Island and Chicago.

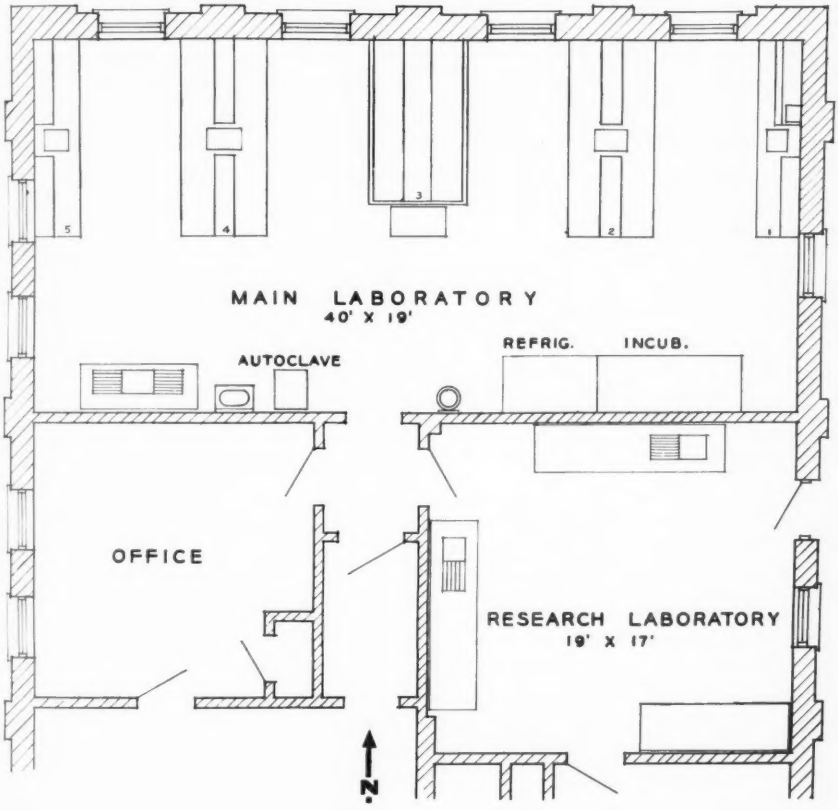
Vaults and Record Rooms.—Space in the form of vaults or record rooms for filing and storing of laboratory and plant records were built at Washington, Buffalo and Chicago. Provision for this detail is undoubtedly made in the office space of the other laboratories.

The desirability of dividing the working space of a sewage works laboratory into many small rooms is open to question. It was our feel-

ing at Chicago that the work of a special research laboratory, unless it is equipped for large or semi-plant scale experiments, as are the research laboratories at Minneapolis-St. Paul and Washington, can be done as well and as efficiently in the general laboratory. Hoods, digestion racks, and balances are as a rule most serviceable when "spotted" close to their points of use.

Laboratory Layouts

The general floor plans of these seven typical laboratories are shown in Figs. 1 to 7. Scales in feet are shown on each drawing and hence



SEWAGE TREATMENT LABORATORY
DEPARTMENT OF PUBLIC SERVICE · · · COLUMBUS, OHIO

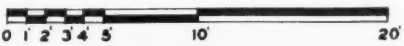


Fig. 1.

it is possible to visualize the relative sizes of these laboratories and the arrangement and sizes of the fixed work benches and equipment. The advantageous arrangement of these fixed benches and equipment is important in reference to routing the samples through the laboratory for routine analyses.

The Columbus Laboratory (Fig. 1) offers the simplest solution for convenient routing of samples. Both chemical and bacteriological analyses are made in a single room. Samples are carted into the laboratory and if not analyzed immediately are placed in the cooler on the southeast wall.

For analysis the samples are routed first to the table at the east side of the laboratory, which is equipped for B.O.D. dilutions and is convenient to the 20° incubator. The samples move westward to Table 2, which is provided with water-suction pumps and vacuum cocks, for suspended solids filtrations. The balance and fume hoods (Table 3) which contain the muffles and drying oven, are centrally located, a very advantageous and desirable arrangement. The two tables west of the fume hood (4 and 5) provide ample room for titration, plating, etc. All the tables are perpendicular to the north wall and are placed between the windows to take advantage of the north light. A large wall sink for washing of bottles and equipment is built on the southwest wall.

The layout of the Cleveland Laboratory is given in Fig. 2. Samples for chemical analysis are very probably brought directly into the B.O.D room which is provided with a dilution bench. From there they are taken into the main laboratory for completion of the analysis. Some of the convenience in making the chemical analysis is lost by isolating the balance, hoods and digestion equipment from the other fixed equipment. The location of the preparation room next to the bacteriological laboratory with a connecting door is an ideal arrangement and facilitates the analysis of bacteriological samples.

Figure 3 shows the arrangement of fixed equipment at the Minneapolis-St. Paul Laboratory. Samples are brought up the dumb-waiter and carted across the corridor to the biochemical laboratory. This laboratory is conveniently equipped with a "truck-refrigerator," dilution bench, 20° C. incubator, filtration bench, and titration bench for B.O.D. dilutions, suspended solids, etc. Kjeldahl digestions and distillations and ignitions are provided for in the hood room. Here, as in the Cleveland Laboratory, the maximum convenience may not be obtained because of the separation in different rooms of the operations necessary for complete analysis.

In the Washington (Blue Plains) Laboratory (Fig. 4) the samples are brought to the second floor on an electrically operated dumb waiter directly into the chemical laboratory. A constant-temperature room large enough to allow for the dilution of B.O.D. samples opens into the laboratory at the southeast corner. A long center table is provided with vacuum for suspended solids filtrations. The fume hood contain-

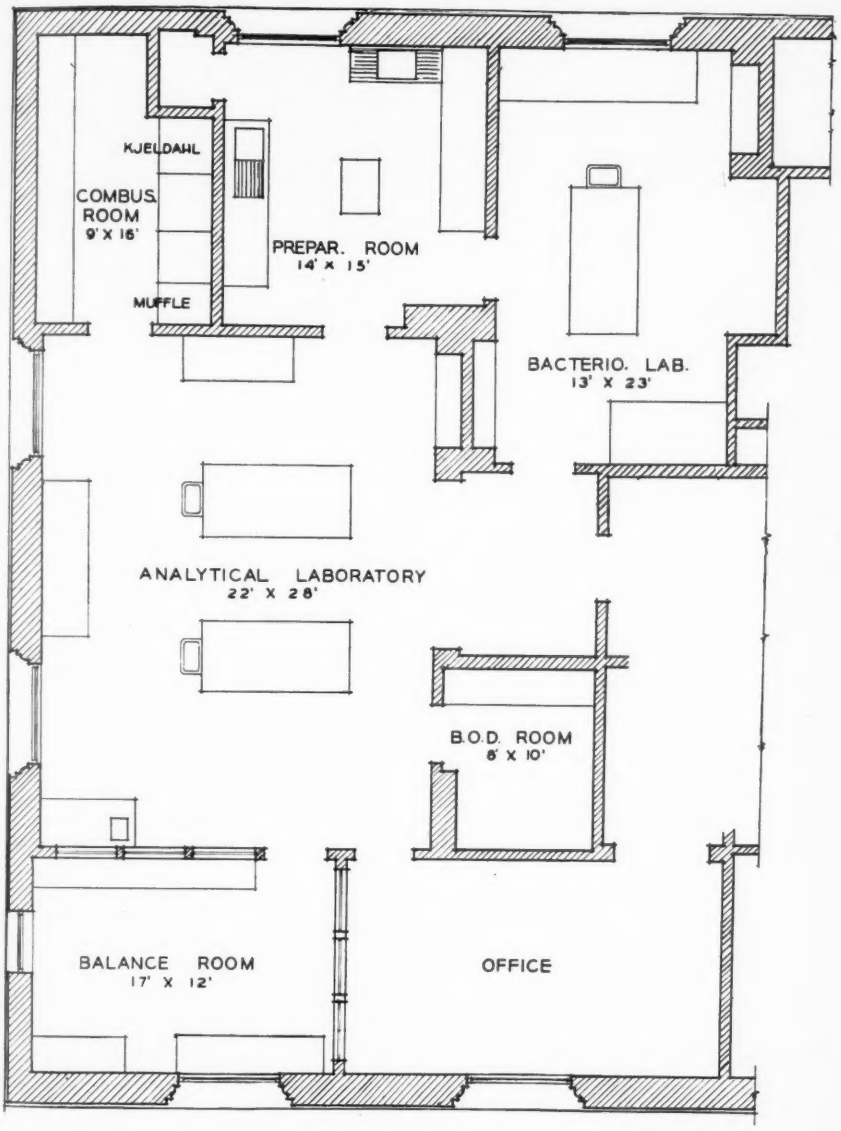

KJELDAHL
COMBUS. ROOM
9' X 16'
MUFFLE
PREPAR. ROOM
14' X 15'
BACTERIO. LAB.
13' X 23'
ANALYTICAL LABORATORY
22' X 28'
B.O.D. ROOM
6' X 10'
BALANCE ROOM
17' X 12'
OFFICE
SEWAGE TREATMENT LABORATORY
DEPT. OF PUB. UTIL.···· EAST PLANT ···· CLEVELAND, OHIO
0 1 2 3 4 5 10 20

FIG. 2.

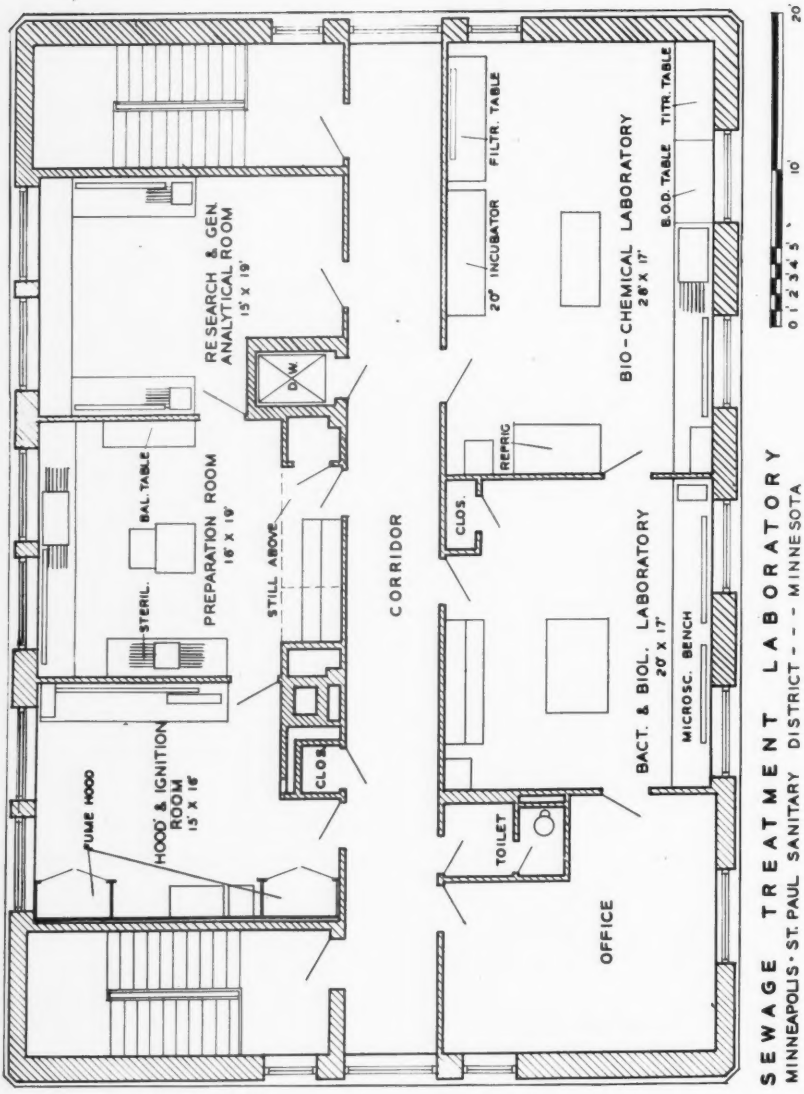

SEWAGE TREATMENT LABORATORY
MINNEAPOLIS · ST. PAUL SANITARY DISTRICT - - - MINNESOTA
RESEARCH & GEN. ANALYTICAL ROOM 15' X 19'
PREPARATION ROOM 16' X 19'
HOOD & IGNITION ROOM 15' X 16'
BAL. TABLE
STERIL.
FUME HOOD
STILL ABOVE
CLOS.
D/W
CORRIDOR
CLOS.
REFRIG
20' INCUBATOR
FILTR. TABLE
BIO-CHEMICAL LABORATORY 28' X 17'
B.O.D. TABLE
TITR. TABLE
BACT. & BIOL. LABORATORY 20' X 17'
MICROSC. BENCH
TOILET
OFFICE
0 1 2 3 4 5 10 20

Fig. 3.

ing the muffles, etc., is conveniently located in the middle of the room. A special room is provided for fine balances.

In planning the Buffalo Laboratory (Fig. 5) more attention was paid to providing a maximum of convenience for bacteriological routine. Samples are brought up the dumb waiter directly into the preparation rooms and carted for bacteriological analysis to the adjoining bacteriological laboratory where ample and convenient provision has been made for plating, tubing, microscope studies, etc. Provision for

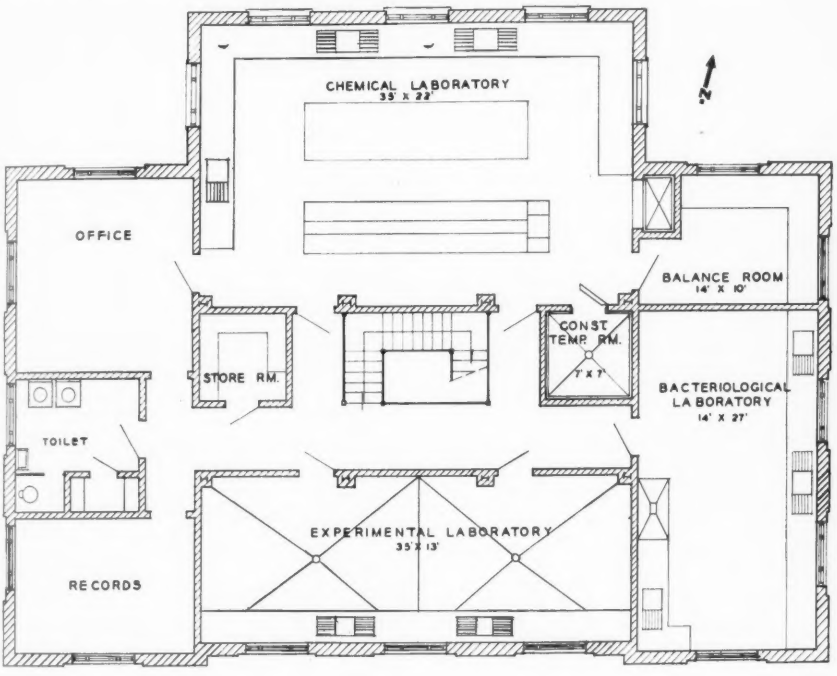


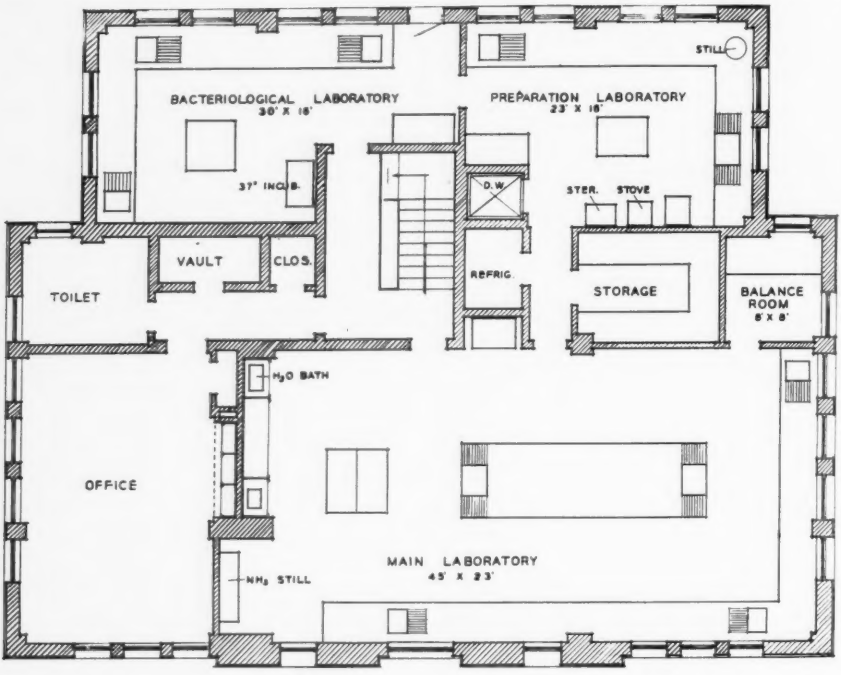
FIG. 4.

B.O.D. dilutions is made on the northwest part of the "L" shaped wall table in the main laboratory. Filtration of suspended solids will be made on the center table. Kjeldahl digestion and distillations, and Nesslerization are very conveniently grouped at the south end of the laboratory. A separate fine-balance room is provided.

The general laboratory of the Ward's Island plant (Fig. 6) is a "U" shaped room with the B.O.D. incubator, storeroom, and dark room forming the middle portion of the "U." Samples can be brought to the south wing for storage or dilution if analyses are to be made im-

mediately and the diluted samples may be placed in the incubator which is just opposite the south counter. The samples are then taken to the north wing where balances, vacuum, digestor, and Kjeldahl still are conveniently located for completion of the analysis.

The equipment at the Chicago Southwest Side Laboratory (Fig. 7), was arranged in groups to afford a maximum of convenience in routing the samples through the laboratory for routine analysis. The laboratory occupies the fourth floor of the Pump and Blower Building.



SEWAGE TREATMENT LABORATORY
BUFFALO SEWER AUTHORITY · · BUFFALO, NEW YORK

0 1 2 3 4 5 10 20

FIG. 5.

Samples reach the laboratory by elevator on the east side of the building and are carted to the west side of the laboratory to the entry desk for recording and numbering. Then beginning at the dilution bench in the extreme northwest corner of the laboratory, samples are passed in succession through the B.O.D. group, the suspended solids group and the nitrogen group. These divisions are referred to as groups because in laying out the fixed benches and equipment an effort was made to concentrate the different pieces of equipment necessary to perform a complete operation. Thus the B.O.D. group consists of dilu-

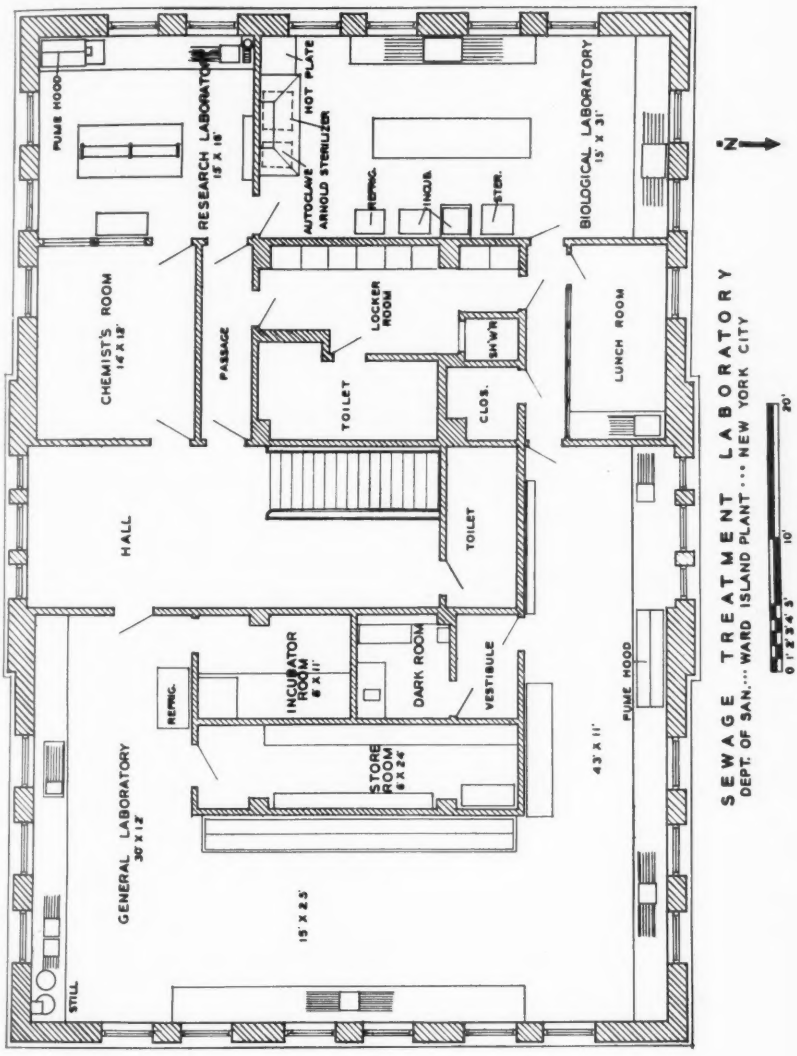

FUME HOOD
RESEARCH LABORATORY 15' X 18'
AUTOCLAVE
ARNOLD STERILIZER
HOT PLATE
REFRIG.
INCUB.
STER.
BIOLOGICAL LABORATORY 15' X 31'
N
CHEMIST'S ROOM 14' X 12'
PASSAGE
LOCKER ROOM
SH'WR
TOILET
CLOS.
LUNCH ROOM
HALL
TOILET
INCUBATOR ROOM 8' X 11'
DARK ROOM
VESTIBULE
REFRIG.
STORE ROOM 8' X 24'
FUME HOOD
43' X 11'
GENERAL LABORATORY 30' X 12'
15' X 25'
STILL
SEWAGE TREATMENT LABORATORY
DEPT. OF SAN.··· WARD ISLAND PLANT··· NEW YORK CITY
0' 1' 2' 3' 4' 5' 10' 20'

FIG. 6.

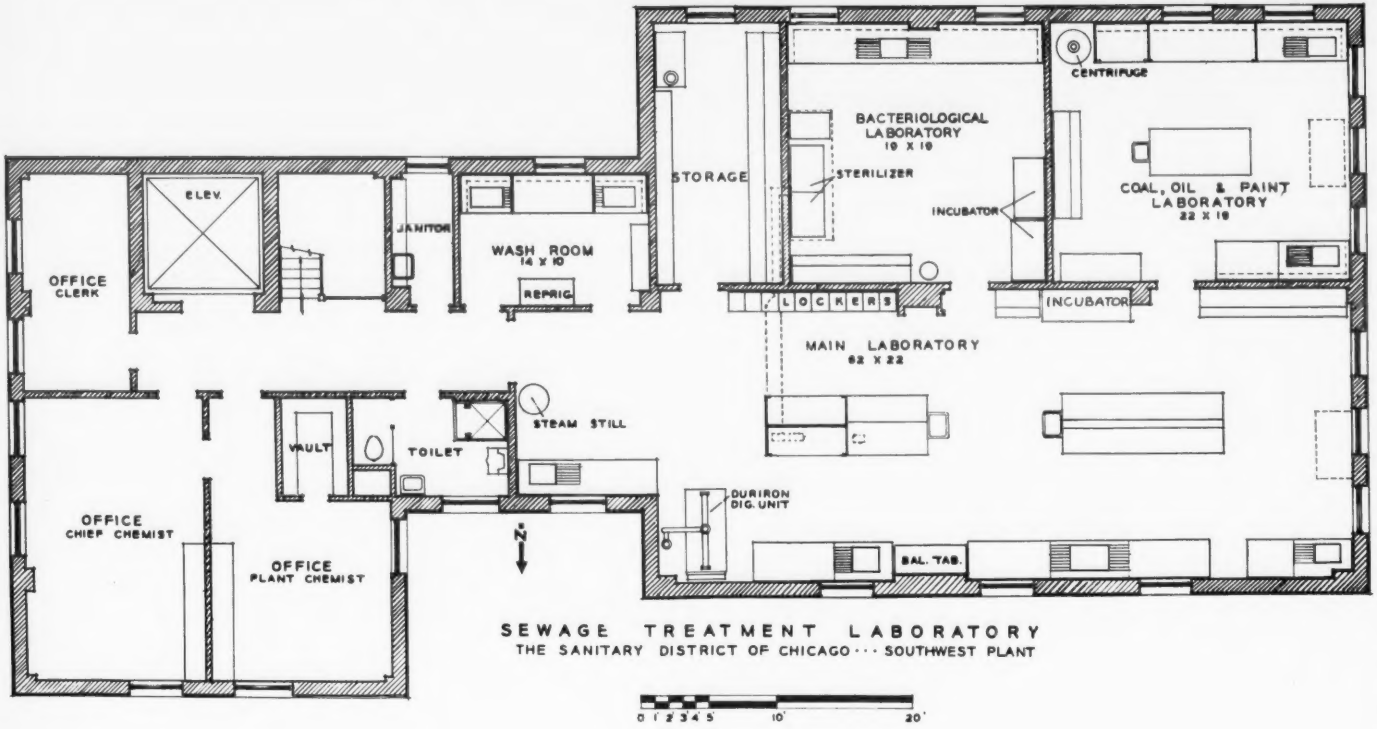

ELEV.
OFFICE CLERK
JANITOR
WASH ROOM 14 X 10
REFRIG.
STORAGE
BACTERIOLOGICAL LABORATORY 19 X 19
STERILIZER
INCUBATOR
CENTRIFUGE
COAL, OIL & PAINT LABORATORY 22 X 19
LOCKERS
INCUBATOR
MAIN LABORATORY 62 X 22
VAULT
TOILET
STEAM STILL
DURIRON DIG. UNIT
BAL. TAB.
OFFICE CHIEF CHEMIST
OFFICE PLANT CHEMIST
N
SEWAGE TREATMENT LABORATORY
THE SANITARY DISTRICT OF CHICAGO · · · SOUTHWEST PLANT
0 1 2 3 4 5 10' 20'

FIG. 7.

tion bench, 20° C. incubator and titration bench. The suspended solids group is composed of a balance table, filtration table, 103° C. oven, and hood and muffle. The nitrogen group is formed by the Kjeldahl digestor, Kjeldahl still, titration and Nesslerization bench. Grouping the fixed equipment in this way not only facilitates the routing of samples through the laboratory but also provides a maximum of convenience for the chemist. This becomes important when it is realized that the chemist charged with the work of determining B.O.D. sets up as many as thirty samples a day and makes three or more dilutions on each. In addition he makes some 200 to 250 dissolved oxygen determinations. The chemist assigned to suspended solids determinations analyzes his thirty samples in duplicate and in addition determines total solids, pH, alkalinity and chlorides when necessary. The chemist charged with nitrogen determinations analyzes these thirty samples for both Kjeldahl nitrogen and ammonia and is responsible also for making up and checking all standard solutions.

In laying out the coal, oil, and materials testing laboratory the same considerations were applied. The equipment was grouped to provide a maximum of convenience for the chemist responsible for these analyses. The bacteriological laboratory was planned as a complete unit. Both preparation of media and bacteriological analyses are performed in the same room.

Facilities for washing the large number of sample bottles, B.O.D. bottles and other glassware required for our work was provided in a separate wash room. This room also houses the sample-refrigerator.

Furniture, Tables and Equipment

There seems to be a trend toward the use of steel for laboratory furniture. At Columbus, Cleveland, Minneapolis-St. Paul, Washington, and Ward's Island a lead-coated copper-bearing steel with baked enamel finish was specified. At Columbus aluminum was chosen as the color. The others selected olive green.

At the Chicago Southwest Side Laboratory and at Buffalo the cupboards of the work benches and the wall cabinets are kiln-dried oak finished in a silver gray, treated so as to bring out the natural grain of the wood. This gives a pleasing serviceable finish which we believe is far superior to the standard golden oak finish. The same silver-oak finish was applied to the doors and woodwork of the laboratory, thus providing a uniform and attractive finish throughout the entire laboratory.

Soapstone table tops 1¼ in. thick were specified at Cleveland, Minneapolis, Washington and Ward's Island, except for certain tables designed for special use such as balance and titration tables.

At Columbus an acid-resistant asbestos top, made by uniting Portland cement, inert filler and asbestos fiber under heavy hydraulic pressure, was used. The monolithic sheet thus formed is impregnated throughout with a bituminous material. Because the use of material

of this kind is comparatively new the specifications required that it be subjected to rigid chemical tests before acceptance. The thickness of the table top is 1¼ inches.

Experience gained at other laboratories of the Sanitary District with both birch and soapstone tops led to the choice of birch for the Southwest Side Laboratory. These tops are constructed of 3-inch strips of seasoned birch, 1⅝ inches thick, which are splined and glued together under heavy pressure. They are bolted at each end of the table and on each side of sink openings with concealed bolts running entirely through the table top. The bolts are so constructed as to exert a pressure automatically on the table top to prevent spreading or warping due to expansion or contraction. The birch is finished with a carbonized black acid-proof finish followed by a coat of hot paraffin.

The table tops at the Buffalo laboratory are also of birch, constructed as described above.

It has been the experience at Chicago that neither wood nor soapstone drainboards or top for B.O.D. tables are able to withstand the severe attack of acid and alkali to which this equipment is subjected and after a short time it was always found necessary to cover them with lead. As a result of this experience lead drainboards and a lead top for the B.O.D. table were specified for the Southwest Side Laboratory. In the other laboratories it was the general practice to form the drainboards by grooving the soapstone table tops at the sinks.

Chemical stoneware sinks were used at all laboratories except Washington. These sinks are made in one piece of a non-porous, non-absorbent, acid proof stoneware. Soapstone sinks were provided at Washington.

Asphalt tile was used for floor coverings at Buffalo and Washington; cork tile was provided at Columbus; rubber tile at Minneapolis-St. Paul. The floors at the Cleveland Laboratory and the Chicago Southwest Side Laboratory are covered with battleship linoleum ¼ in. thick. Linoleum was selected for Chicago because of the extraordinary service it provided at the Main Laboratory. The linoleum stood up under severe use for about ten years and was still serviceable when the laboratory was moved. Only concentrated caustic solutions were found to attack it severely.

Laboratory equipment is so well standardized that only a brief statement will suffice. There is a general tendency to use electrical equipment. At Chicago, where it is expected that the cost of production of electricity will be very low, electrical equipment was specified wherever possible. The heating elements of the Kjeldahl digestors and stills are electrical units provided with individual rheostats to secure a maximum degree of control. A single rheostat for the whole bank of burners is not very satisfactory.

On the other hand at Buffalo where it is expected to trap the gas from the sludge digestion units, gas was specified wherever close thermostatic control was not necessary.

There was a unanimous choice of Duriron equipment for the Kjeldahl digestion units. However in all the laboratories but Chicago these units were put under a hood for safety. At Chicago, the twenty-four unit digestor is used in the open and to date no need for protection other than that provided by the Duriron exhaust fan has been found necessary.

Both gas and electric water stills were selected at the various laboratories. At the Chicago Laboratory advantage was taken of the high pressure steam which will be generated to operate the turbine driven pumps and blowers, and a steam still capable of delivering five gallons per hour at 12 pounds pressure and 10 gallons at 20 pounds pressure was provided.

Acknowledgments

I wish to express my sincere gratitude to Mr. George Schroepfer, Assistant Chief Engineer of the Minneapolis-St. Paul Sanitary District; Mr. Paul McNamee, Chemist at the Washington Laboratory; Richard H. Gould, New York Department of Sanitation; Robert A. Allton of Columbus; George O. Jones of Cleveland; and S. A. Greeley, designer of the Buffalo Plant, for furnishing plans and specifications of these laboratories.

I also wish to express my appreciation to Dr. Mohlman for his aid and suggestions in planning this paper and to T. H. Finlayson for preparation of the figures included in the paper.

The Southwest Side Laboratory of the Sanitary District of Chicago was built under the direction of Mr. Wm. H. Trinkaus, Chief Engineer. Mr. Joshua D'Esposito, Resident Project Engineer, represented the Public Works Administration. The plans and specifications for the Southwest Side Laboratory at Chicago were prepared in the Architectural Division of the Sanitary District under the direction of T. H. Finlayson, Architect, in collaboration with Dr. Mohlman and the writer.

ASPECTS OF SEWAGE CHLORINATION IN 1937 *

By Linn H. Enslow [1] and Harry A. Faber [2]

From modest recognition as a disinfectant, in the early years of sewage treatment, the chlorination process has developed to serve a number of other important purposes in sewage disposal practice. During the past ten years, in particular, the growth of this process has been not only extensive but conservative, and fundamentally sound as well. Research under competent direction and operating results, based on many different conditions, has served to establish new and valuable applications for chlorine in sewage treatment.

The numerous articles concerning chlorination, which have been published in various technical journals, represent contributions to a better understanding of the possibilities and limitations of the process. Many of these deserve mention, but only a few of the most outstanding can be indicated here. A paper in the *Sewage Works Journal* of 1931, by Geo. B. Gascoigne, amongst other things, attested to the permanent reduction in oxygen demand accomplished by effluent chlorination. The comprehensive review by the Committee on Sewage Disposal of the American Public Health Association, headed by Langdon Pearse, and published by the Association in 1934, stands as an authoritative survey of chlorination in sewage treatment up to that time. Valuable detailed studies of the mechanism of disinfection, and the effect of contact and mixing time, have since been contributed by Rudolfs and his co-workers in the New Jersey Experimental Station Bulletins.

Principal Uses

Disinfection to destroy pathogenic and other bacteria still stands as the pre-eminent use of chlorine (Fig. 1). For this purpose it may be applied prior to or following other sewage treatment processes, as may be required by local conditions.

The present application of chlorine next in importance is to prevent or delay septicity of raw sewage. Reasonably fresh sewage is not only unobjectionable from an odor standpoint, but since it contains little if any hydrogen sulfide it does not destroy concrete or masonry sewers. The use of chlorine at up-sewer locations to suppress the activity of sulfate-splitting bacteria has come to represent an important contribution to safeguard sewers and assist a variety of sewage treatment methods (Fig. 2). With the application of moderate amounts of chlorine, sewage may be maintained in a fresh state and is thus received at the plant in a condition that renders it more amenable to subsequent

* Presented at the Eleventh Annual Conference of the Pennsylvania Sewage Works Assn., State College, Pa., June 23, 1937.

[1] *Editor, "Water Works and Sewerage," and Engineer Advisor, The Chlorine Institute, Inc.*

[2] *Research Chemist, The Chlorine Institute, Inc.*

purification. The sensitive activated sludge process and bio- or chemical precipitation processes, are particularly aided by the delivery of a non-septic sewage.

The lack of objectionable odors is readily appreciated by both plant operators and plant visitors, but odors are not the only objection to the presence of septic sewage. If sewer lines are long and lack adequate grade, the deposition of solids, or even the age of the liquid portion, will permit formation of hydrogen sulfide in such amounts as to cause sewer destruction. In moist air hydrogen sulfide is biologically oxi-

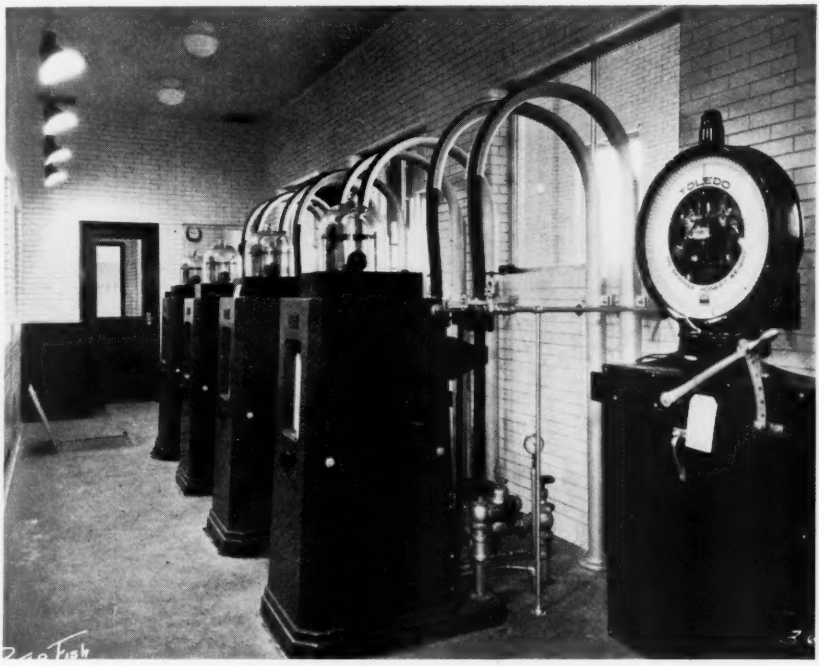


FIG. 1.—Chlorinator room of a modern plant.

dized to sulfurous and sulfuric acids, which readily attack concrete and corrode metals. The economic value of chlorine in preventing such acid disintegration is responsible for its wider adoption.

INDIRECT CHLORINATION

When the up-sewer application of chlorine is inconvenient or impracticable, the indirect application (as ferrous chloride) may be utilized. This procedure consists of passing the discharge from a solution chlorinator through a tower containing scrap iron or tin cans and applying the resulting iron chloride solution to the sewage. In this form the iron possesses the ability of "fixing" the hydrogen sulfide as non-volatile iron sulfide. The use of this treatment at the plant will

eliminate odors and the added iron seems to have distinct value in aiding subsequent sewage treatment processes. In some instances upsewer chlorination is most efficient as a preventive measure. In others the chlorinated iron process, as a corrective procedure, proves more suitable (Fig. 3). Then, under some conditions, the combination of both methods proves best suited to the particular problem. Riker, at Princeton, N. J., utilizing scrap and tin cans from a near-by incinerator, was among the first to demonstrate that the chlorinated iron process was able to cope with a serious odor condition. Chlorinated iron proved less costly and more effective than chlorination of the already septic sewage.

FIG. 2.—Los Angeles county sanitation district has several of these scattered chlorinator-ton container stations chlorinating fresh sewage to keep it fresh. (The ton container is in the "dog-house" behind the chlorinator.)

When desired, the chlorinated iron process (developed by Scott and Darcey at Oklahoma City) may be so controlled as to produce a ferric chloride solution (Fig. 4). This is a valuable coagulant for use in the chemical precipitation of sewage and is especially economical when the plant is not conveniently located to a source of prepared iron coagulants. Container size greatly affects the price of chlorine and, where large amounts are required, ton container and tank car units are obtainable at attractive unit prices. Scrap iron or tin cans are often available for only the cost of handling. The Scott-Darcey coagulant has been most widely adopted in several of the western states, where shipping

distances add greatly to the cost of coagulants. At Oklahoma City ferric chloride, prepared in this manner, has been adopted both for water and sewage coagulation. A more recent large installation is that at El Paso, Texas. The most extensive installation of this process so far attempted will be at the new Denver, Colorado, plant. It is planned to provide the largest part of the iron coagulant by this method, supplemented by chlorinated copperas for variation in dosage requirements.

FIG. 3.—A ferrous chloride generating station located in the corner of a park. (From tin cans and chlorine—the iron chloride produced flows into the sewer to fix the hydrogen sulfide. The iron tower is below the building in the rear.)

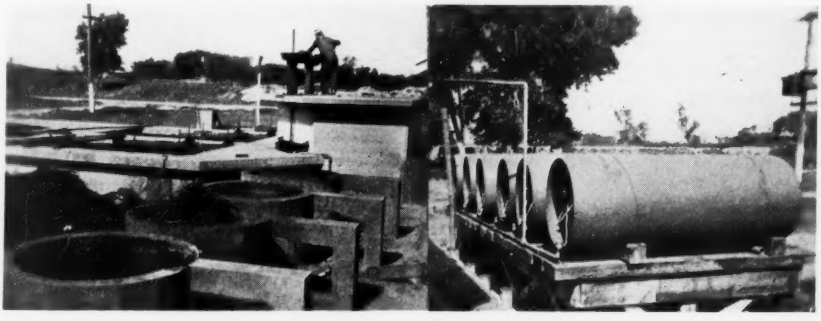


FIG. 4.—A battery of ton-chlorine containers and four iron chloride towers at the Oklahoma City plant, producing ferric chloride for chemical precipitation and odor control.

In many chemical treatment plants chlorinated copperas (ferrous sulfate oxidized with chlorine) has been adopted as an effective and economical coagulant. For this purpose it may be employed either alone or in conjunction with lime. Copperas is available at a reasonable price, presents no handling difficulties, and when in solution reacts readily with chlorine to yield a mixture of ferric chloride and ferric

sulfate. This coagulant has been adopted for the Coney Island plant, of New York City, by the Guggenheim plant at New Britain, and some 3000 tons of copperas will be required for seasonal use at the new Minneapolis-St. Paul plant. Chlorinated copperas is second to ferric chloride in effectiveness for conditioning sludge prior to vacuum filtration, and it will be used for this purpose at Baltimore as well as at the Minneapolis-St. Paul plant.

Chlorine and iron act in other ways than directly upon odors or as a coagulant. It has been found that the presence of iron in sewage aids in accomplishing biological purification on trickling filters. Atlanta, Georgia, has remodeled a veteran plant to use chlorinated copperas to permit a much increased loading on twenty-five year old filters.

Oxygen Demand Reduction

Chlorination of effluents produces a reduction in oxygen demand which may be of particular value for increasing the B.O.D. reduction efficiency of overloaded or partial treatment plants. The formation of addition products such as chloro-proteins which are not susceptible to fermentation, or may even be mild disinfectants, partially explains this property. The improvement is further accomplished through the general retardation of decomposition during the period of greatest rapidity of oxygen depletion in the receiving stream. Even when chlorine is applied to produce only a partial satisfaction of the chlorine demand, a proportional reduction of oxygen demand will result. The value of such partial chlorination may prove of particular significance during conditions of low stream flow, or where plant facilities are inadequate in certain seasons. A recent illustration is of interest. Partial chlorination has been employed by the city of Bristol in England to eliminate a serious odor condition produced by sludge deposits in the tide-locked river Avon. Although available equipment was able to supply only enough chlorine to satisfy 25 per cent of the chlorine demand of the Bristol sewage, even this treatment proved effective, except for a few days during the warmest summer months.

Partial treatment of industrial wastes has been effectively accomplished by chlorination. Similarly, the chlorination of concentrated digested supernatant liquor reduces the extreme load which this liquor adds to plant operation. As more complex and complete methods of treatment are developed, there appears to be a definite place in which chlorine application proves a distinct aid to the process. For example: Wash water returned from the sludge elutriation process may, when chlorinated, be returned with less load on plant processes and with mild disinfectant action on raw sewage. Further, such unusual conditions as foaming digesters or Imhoff tanks have been corrected by judicious chlorine application. Instances of this use are reported from such widely separated locations as Stockton, Cal., Tonawanda, N. Y., and Westminster, Md. In several cases the pooling of trickling

filters, due to excessive biological growths or to grease accumulation, or a combination of both, has been corrected by chlorination.

Sludge Bulking

It has already been noted that chlorination aids the activated sludge process by maintenance of the influent sewage in fresh condition. Control of certain types of sludge bulking by mild chlorination of the recirculated sludge has already been proved feasible at those plants where bulking has been due to oxygen deficiency in the aerators. Lima, Ohio, was the first to report the successful application of this practice, and similar conditions have been corrected by chlorination at Lancaster, Pa., Hagerstown, Md., and elsewhere. When settled activated sludge at Charlotte, N. C., proved too bulky for the peace of mind of the operator, and refused to filter readily on vacuum filters, the condition was corrected by chlorination of the return sludge.

It is desirable to add to digesters a sludge with a solids content as high as possible. Thickening of sludge by settling prior to digestion accomplishes this purpose, but the growth of gas-producing organisms usually prevents effective thickening. Chlorine has been employed effectively at Phoenix, Ariz., Topeka, Kan., and elsewhere in a sludge thickening process. Bacterial development is inhibited by maintaining residual chlorine in the supernatant water strata of the thickening tank, and this residual chlorine makes possible longer holding of a sludge to produce one of much higher solids content. The same method is now planned for the contemplated Baltimore plant.

Aero-Chlorination for Grease Separation

The newest application of chlorine to be reported is its use, in conjunction with pre-aeration, to increase the separation of grease from sewages and trade wastes. Preliminary studies on a plant scale at Woonsocket, R. I.,* showed that at least four times the ordinary removal was accomplished by this treatment. Extensive study of this procedure is now under way at Baltimore, Md., and elsewhere, and reports reveal that even higher yields are being obtained with more efficient operating conditions. This phase of pre-treatment, involving chlorine injection into the compressed air header pipes leading to pre-aeration channels or grease separators, promises to be of marked significance in connection with the activated sludge process or with bio-flocculation. It is well known that the presence of excessive grease or oil seriously interferes with the efficiency of both processes.

During the past decade the adoption of chlorination has, perhaps, been most stimulated by the flexibility of such treatment. A wide range of purification may be accomplished to meet specific conditions. Whether chlorine is applied preceding other treatment to maintain maximum operating efficiency, whether it is an integral part of the

* Reported by one of the authors in the May, 1937, issue of *Water Works and Sewerage.*

treatment process, or whether it is employed as a final finishing process, it is subject to accurate control. Chlorination during special or seasonal conditions offers a convenient reserve of treatment facilities. Today a wide variety of chlorinating equipment, devised to fit special conditions, is available. Chlorine itself may be obtained in forms ranging from high test hypochlorites to the ton container or the tank car of liquid chlorine. Thus the limitations and results, of what may be accomplished by chlorination, are determined only by the special requirements of the sewage and plant to be considered. Each may justifiably be considered a special case with special problems to be solved in a manner which can best be determined after technical consideration.

THE DISPOSAL OF SEWAGE AND GARBAGE—RELATED MUNICIPAL FUNCTIONS *

By Morris M. Cohn

Sanitary Engineer, City of Schenectady, N. Y.;
Editor, "Municipal Sanitation"

Sewage treatment has moved along so far and so fast that it may seem too elementary to revert to the basic ABC's of the art and science. Yet, such a retrospect should be valuable to a profession that owes its successful first starts and its successful re-starts to untiring workers who have always returned to basic concepts before approaching investigations of new processes in sewage treatment.

We are, in a way, victims of intense specialization. We have been so steeped in the complex biological, chemical and mechanical sciences of our past that we are in danger, frequently, of seeing treatment as an entity within itself, rather than merely a means towards an end. We are much like the two youngsters who, in the heat of a street fight, forget the cause of the quarrel and the clarification of the issue which the fight was intended to settle.

In short, a profession that pulses with the life that it serves, and with the life which it hopes to perpetuate by the elimination of stream pollution, owes it to itself to keep sight of the peculiar conditions which leave their impress on the sewage which it treats. Therefore, gentlemen, if I have not yet drowned you in the depth of my sewage argument, I would like to introduce you to *sewage,* the commodity with which we deal.

Every committee that has defined sewage has made the mistake of applying to it a definiteness that belies its indefiniteness. Sewage is the product of life; it changes with the life habits of the producers. It can not be more homogeneous than the heterogeneous life which produces it.

The sewage flow reflects the life of the community. From the day that the first water-carried waste went flowing through the first drain, until the present day of subconscious use of sanitary facilities, every change in living conditions has been reflected in the sewage flow. The sewage of today is not the sewage of a score of years ago, no more than our present habits of life are those of grandfather's time.

There is one thing about sewage. . . it reflects the big changes as well as the trivial. The glorious rise in the standards of living, the sweeping revamping of the industrial world, the restrictions of a constitutional amendment, the pinch of depression . . . all are reflected fully as exactly as is the never-say-die spirit of the tomato seed.

These changes in sewage characteristics we have taken in our stride. Many of them have come upon us unnoticed, because we, as a portion

* Presented at the Eleventh Annual Conference of the Maryland-Delaware Water and Sewage Association, Wilmington, Del., May 7, 1937.

of life, have been subjected to the same changed living conditions which have produced new and different characteristics in sewage. We have been a portion of the life which has converted the Saturday night bath to the twice-a-day needle-point shower. We have been a portion of the life that has changed the cook stove age to the can opener era. We have been a portion of the life which has seen the horse go out and the auto come in, with its excreta of spent oils and unspent gasoline. We may be excused for our inability to enumerate sewage constituents which are "normal" and those which are "foreign" when we realize that everything that we do in the home, in the industry, and in our own personal hygiene habits have had their effect on our liquid wastes.

Much sewage has gone over the effluent weir since the first officials, in their grave doubts about the workability of sewers, attempted to shield their untried conduits from services that looked particularly difficult. The first sewers were built specifically for drainage water. The addition of human wastes were outlawed by those who viewed sewers as long tubes, at one end of which people were putting things in, and at the other end of which crazy men were trying to take them out. I do not know whether North Carolina played a part in some of the early rules prohibiting the use of sewers for certain purposes and during certain seasons, but such rules were partially promulgated for the purpose of protecting sewers from injury.

Why all of this discussion about sewage and its changing characteristics? Simply because it serves as an ideal springing-board into a discussion of the sanitary engineers' deliberate and premeditated attempt to change the character of sewage and its residue. A homely discussion of the progressively interesting changes in sewage character should serve as a highly satisfactory introduction for a discussion of the engineers' latest interest in the combining of sewage and garbage into a new type of sewage flow. After years of watching sewage change because of changed conditions in the homes, commercial establishments and industries connected to public sewers, we are faced, at last, with the first attempt on the part of engineers to do a bit of changing themselves.

It is my intention to show that there is nothing unusual or unorthodox in a combination of sewage and properly prepared garbage. I trust that my simple presentation will prove that the present trend towards the combined disposal of sewage and garbage is merely a reemphasis of conditions that today exist, rather than a change in the conditions themselves.

May I tell you a simple story to illustrate what I mean? It appears that an individual desired to purchase a well known stock that was being quoted on the market at a price of $40 a share. Having a friend in Florida who was recognized as a market authority, the prospective purchaser wired his friend asking him whether the price was a satisfactory one. The prospective buyer received a telegram from his friend which read—"No price too high"—whereupon he purchased a large block of stock which subsequently was depressed in price at a

large financial loss to him. When the market expert returned from Florida he found his friend in dire financial straights. Upon being accused of giving the wrong market advice, he stated that he had warned his friend not to buy at the price by wiring, "No. Price too high." Because of lack of emphasis, our friend of the stock market lost his money. Because of lack of emphasis, we may misunderstand the basic significance of the combined disposal of sewage and garbage. It is my hope to clear up this misunderstanding, if such a misunderstanding does exist.

The sewage works operator and sewage works designer has had his own worries without delving into the other basic municipal problem of garbage disposal. As a result, his interest in garbage has been negative, rather than positive. Prior to the construction of public sewers and treatment works, the outhouse and the garbage can were probably neighbors. The waste which the human body discarded and the waste which a human discarded, or in other words—*sewage* and *garbage,* were either buried in similar fashion, or accumulated for collection. It is questionable whether the collector of night soil was less recognized as a member of society than the collector of garbage.

With the advent of public water supplies and the blessing of running water in the home, human wastes were removed instantaneously, efficiently, unseen from the home. The sewage works operator was born. The garbage can remained ensconced in the backyard and the gulf of difference between sewage and garbage widened.

In order to make more certain of the complete separation of sewage and garbage, some cities introduced legislative restrictions against the discharge of the latter material into sewers and drains. The engulfing depths of the sewers, however, have induced citizens to discharge wholesale quantities of mass garbage, mixed with such trifling odds and ends as mattresses and baby carriages, into the flowing stream. It is reported that such actions by an enterprising collector who possessed a big route but no dump facilities, induced the Sanitary District in Springfield, Ill., to enact an ordinance prohibiting the discharge of garbage into sewers.

Ordinance or no ordinance, the housewife has seen in her toilet, a means for the instantaneous disposal of much food waste. While the practice of disposing of food wastes in this manner is not universally used, there is sufficient true food waste carried into sewers to make the treatment works look like a garbage plant, at times. During one day, the writer hand-picked the following items of garbage from the Schenectady bar-rack trash: large pieces of cooked turnips, large pieces of spaghetti, peas, carrots, stalks of celery, half of a lemon, butter beans, chicken innards, orange peel, potato peelings, pickling spices, dill pickle, half of a green pepper, tea bags, piece of an apricot, pieces of fat meat, pork rind, dandelion greens, nut meats, peanut shells, mushrooms, dead gold fish, half frankfurter, pieces of bread, olives, etc. Enough items were found to bring the total to some 100 distinct varieties of waste food in the trash, on the surface of the Imhoff tanks and

in the tank gas vents. Every sewage works operator has had similar experiences. Previous reporting of this interesting list of food materials has led a number of operators to make similar surveys and to report their findings to me. Seriously or humorously, this "treasure hunt" tells us much about the character of sewage. Every operator knows of the presence of this material, every operator views this material as a legitimate constituent of his sewage flow. The presence of so much food in sewage is a true indication that garbage and sewage are similar materials.

Basically, domestic sewage is human waste (fecal matter and urine), dishwashing waste, laundry waste, body cleansing waste, and waste of home cleaning. Human wastes and dish water wastes are strangely alike in the test tube. The food that enters the home leaves it—in either the form of garbage or body waste. Basically, the material in the garbage can and the human waste in the sewers are similar chemically. One waste has not been subjected to body metabolism, the other has. Both wastes are highly organic, subject to decay, breeders of insects and flies, and producers of odors, both are high in water content, both are capable of digestion.

Larger remnants of food go into the garbage cans during preparation of meals, smaller particles may go through the perforated plate in the sink, and thence into the drain. The potato that goes to the can is the same potato which, in mashed form, is washed off the dinner plate and enters the sewer. The coffee liquid goes to the sewer, the grounds sometimes to the sewer and sometimes to the garbage can. The balance of the vegetable soup goes down the drain, the original vegetables, if rejected, might go to the garbage can. So it goes. So, by these homely examples, we indicate the close bond that exists between sewage and garbage. In short, we can defy anyone to sort the food particles from the sewage and say, "These are not sewage."

We have, up until this point, determined that sewage is a product of life; that life is ever changing; that sewage reflects these changes in life; and that the sanitary engineer has taken these changes graciously and accepted them as a natural result of the life which it is his solemn function to serve. We have referred to the new interest in the combined disposal of sewage and garbage and seen in this interest the attempt of the engineer to himself take a hand in shaping the changing characteristics of sewage. We have reviewed the character of sewage and made an inventory of the large quantities of food wastes which, while constituents of the sewage flow, are strangely similar to the food wastes contained in a garbage can. This elementary consideration of the problem should lead us to the conclusion that the relating of sewage and garbage disposal is not rank professional heresy; that there is little true scientific justice in the smug attitude that we have enough troubles in sewage plants now; why add garbage to the sewage and give us more? We have these materials separated, why put them together, only to have the task of removing them again? Perhaps our elementary consideration will see in this complacent attitude an echo of those

doubting Thomases who once said much the same thing about adding human waste to sewers.

Methods of Combining Sewage and Garbage

The engineer does nothing by half measures. Becoming interested in a problem, he investigates every phase of it, all for the purpose of finding the best, the most economical, the most serviceable method of doing the proposed task. So it is with the combined disposal of sewage and garbage, or food-wastes.

In all, there have been proposed and already used four different methods of making these two disposal tasks related municipal functions. Not content with trying just one method for combining these two materials or the treatment of these two materials, the engineer has investigated the feasibility and desirability of these four methods:

1. Municipal grinding at central stations.
2. Household grinding of fresh food wastes.
3. Grinding at the sewage plant, for incineration of pulp, for introduction of pulp into sewage flow, or for introduction of pulp into digesters.
4. Sewage-refuse plants in which the disposal of the two materials is carried out separately, but in which various phases of the disposal processes are inter-dependent.

The first method involves the storage of the garbage in the home, as in the past, its collection and transportation to the nearest feasible point of grinding and discharge into the sewer system for transportation to the treatment plant. The second method involves the immediate grinding of the food-wastes in the home for flushing into the sewer system, just as the present sewage is flushed into the sewer system by means of our present plumbing fixtures, thus merely adding another constituent to the flow. The third method involves the storage of material in the home, the collection of the material as usual, and the transportation to the sewage plant for final disposal. The fourth method also involves hauling to the plant, but delivery to a garbage plant on the site.

Central Grinding Stations

Much interest has been shown recently in the municipal disposal of garbage by means of central grinding stations. Advocates of the process stress the savings possible in collection costs, due to shortness of haul and the advantages of using the sewage treatment plant for the combined disposal of both sewage and garbage.

Many descriptions have been given of central grinding stations. The station involves facilities for the discharge of garbage from trucks, facilitates for the transfer of the stored garbage to hoppers, and facilities for the movement from the hoppers into the grinding mechanism. The grinding mechanism may consist of a swing hammer mill or a rotary shear mill.

The central grinding station method of garbage disposal has been tried on a practical scale. In 1923, the first known municipal grinding operations were performed at Lebanon, Pa., at which time garbage was ground, discharged into sewers and delivered to an Imhoff type sewage treatment plant. No further progress was accomplished until 1933, when the City of Baltimore built and operated a garbage grinding plant to relieve the municipal incinerator of the peak summer loads. Reports by Keefer indicate that during a 24-day period, a total of 1,693 tons of garbage were ground and discharged through a 24 in. sewer into the city sewer system. The City of St. Louis has been grinding garbage, either wholly or in part, since February, 1935, and discharging the material into sewers leading directly to the Mississippi River. No treatment of the sewage has been provided at St. Louis, and controversy has arisen between the city and federal fishery agencies.

Perhaps the most striking demonstration of the feasibility of central grinding station operation has been supplied by the city of Indianapolis. There, for a period of seven months, all of the garbage produced by the city has been ground in a hammer mill, and discharged into the trunk sewer leading to the aeration-activated sludge plant.

It is reported by Calvert that a total of 17,256 tons of garbage were discharged through the grinding plant into the trunk sewer. While it is not intended here to discuss the effect of this garbage grinding process on the sewage plant operation, it is interesting to quote Mr. Calvert's statement that "the data do not indicate that the process of sewage treatment was improved by the addition of garbage, that there is also no indication that the garbage caused disruption of the activated sludge process."

The active and pioneering state of North Carolina is not without its own demonstration of the feasibility of the grinding of garbage in municipal stations for ultimate discharge into the sewer system. It is reported that the City of Durham has periodically ground garbage for introduction into the sewers and for ultimate handling by the sewage treatment plant, and that the addition of this material has increased appreciably the yield of gas in the sludge digesters. It is my hope that Mr. Piatt or any other Durham representative may add the interesting story of Durham's pioneering work on this subject to my sketchy review.

Household Grinding

Perhaps one of the most interesting innovations of the present age is the development of a household grinder for the purpose of properly pulping waste-foods in the home, and immediately discharging this material into the public sewer system via the home plumbing system. Advocates of the process point out that the instantaneous disposal of food wastes in the home eliminates the garbage can from the American home, and eliminates also the unhygienic conditions which are associated with the garbage can. It is pointed out that, just as modern

plumbing facilities offered immediate freedom from the dangerous, putrefactive, nauseating waste of the human system, so the new household grinder provides similar desirable freedom from the household's companion waste, garbage.

The device consists of a waste receiving compartment, a grinding compartment, and a motor, all in one assembly, which is connected to the sink drain. The device is installed under and directly attached to the kitchen sink.

The unit disposes of approximately one pound of normal food waste per minute of operation, and utilizes approximately two gallons of water per capita per day. The discharged pulp is finely divided, water-buoyant and air-whipped. The high speed grinding assures proper mixture of the water and the solids, and the centrifugal action results in a mechanical burnishing of the interior of the grinder itself.

Significant of the municipal acceptance of this new innovation are the recent actions of the City of Los Angeles, and of Riverhead, N. Y. Los Angeles has recently legalized the disposal of ground garbage into sewer systems, and has established ordinance requirements covering the fineness of the pulp which is to be so discharged. City Engineer Aldrich stated: "Realizing that it is only a matter of time until the present unsanitary and unpleasant methods of disposal of domestic garbage by semi-weekly collections will be abandoned in progressive neighborhoods in favor of disposal of garbage in a finely ground condition immediately after the waste food is produced and without storage, via a kitchen sink and a sanitary sewer system," the city provided formal legalization of this new process. In the case of Riverhead, a new sewer code prohibits the discharge of *unground* garbage into the sewer, but permits the discharge of properly pulped material produced by a satisfactory household mechanical grinder. Here, indeed, is evidence the engineer may be willing to vary the character of sewage but he insists on doing the job according to his own specifications.

It is reported by users of the new household grinder that the plumbing system effectively handles this material, and, in fact, that the discharge of this material through the plumbing drain actually results in the elimination of a previous sluggish condition. It is estimated that universal use of this process might increase the water consumption of a community by approximately 2 per cent.

While this process is particularly interesting because of its close relationship to the development of the household plumbing system which has resulted in the improvement of health and the enhancement of personal cleanliness and personal fastidiousness, it is readily understandable that this process will not become universal within the life span of any one of us. The cost of this device is far beyond the purchasing power of the run-of-mine community population, and it has been estimated that the next score of years may result in its use by only some 10 per cent of the population.

On this basis, it will be many years before this new process of disposing of food waste from the home will have any significant effect

upon the sanitary problems of the community. In the meantime, present methods of garbage disposal or modified methods of garbage disposal will be utilized and the household disposal method may be viewed as a benefit which will be utilized only by those who desire this service.

Viewed in this light, the use of household grinders becomes a matter of personal choice which need not seriously affect the municipal problem of garbage disposal. The process is particularly interesting to the sanitary engineer, because it utilizes the time-tried water-carriage system for the disposal of one more waste from the home. It has advantages in home hygiene and community cleanliness which endear it to the profession. That its adoption will be slow should not alter the attitude of the profession which holds dearly its ability to serve the public and to foster any process which will result in future benefit to the race.

Grinding Stations at Sewage Plants

The actual mechanics of grinding garbage at a sewage treatment works for ultimate disposal either with the sewage or with the sewage residues, is similar to that practised at central grinding stations located along the route of public sewers. However, in the case of grinding at the sewage treatment works, a wide choice is available as to the ultimate disposal of the garbage pulp produced. The material may be discharged into the sewage ahead of grit chambers, ahead of clarifiers, mixed with sludge and pumped to digesters, mixed with sludge for de-watering on vacuum filters, or incinerated directly with screenings or sludge in sewage plant incinerators.

Mark B. Owen in a paper presented before the American Public Works Association in 1936 stated as follows:

"Ground garbage may be discharged into a sludge mixing tank, prior to de-watering by vacuum filters; or it may be discharged directly into the incinerator with de-watered sludge. Nine sewage plants in the United States are or will be equipped to take advantage of this plan. Four of these plants were specifically designed to dispose of sludge and shredded garbage by incineration.

"The sewage works at both Kokomo and La Porte, Ind., designed by Russell B. Moore, Consulting Engineer of Indianapolis, are provided with Nichols Herreshoff furnaces for garbage and sludge incineration. The Kokomo Plant is designed to dispose of 6 wet tons of digested sludge and 7 wet tons of shredded garbage in 17 hours, or the equivalent of 18.4 tons in 24 hours. At La Porte the incinerator is expected to handle 3.64 wet tons of digested sludge and 10 wet tons of shredded garbage per day of 24 hours.

"At Colorado Springs, Colo., Mr. Burton Lowther, Consulting Engineer, specified incinerator capacity capable of burning 16 wet tons of digested sludge and 6 wet tons of shredded garbage per day of 24 hours. In these three cities, grinding equipment will be installed at a later date because of financing problems.

"Immediate installation of garbage grinding and conveying equipment, as a part of the new sewage plant, is contemplated by Greeley and Hansen, Consulting Engineers, for Kaukauna, Wisconsin. During 10 months of the year it is anticipated that 8.3 wet tons of undigested sludge and wet garbage will be incinerated during six hours per day. During two months of the year, 33.33 wet tons of chemically precipitated sludge and ground garbage will be incinerated in 22 hours per day."

It is the writer's understanding that several of these contemplated plants have been completed, and that other plants of similar nature are contemplated.

Sewage-Refuse Disposal Plants

Recently, widespread interest has been evoked in a process of jointly disposing of sewage and garbage as two separate but interconnected plants. This process involves the construction of a municipal refuse incinerator on the site of and in direct contact with the municipal sewage disposal plant. Advocates of this process stress the possibility of financial savings as a result of interlocking operation forces, and the flexibility of operation resulting from the interlocking of the two processes.

In general, the combined sewage-refuse plant consists of an incinerator and a sewage plant of the separate sludge digestion type. Interlocking of the two municipal processes include the utilization of incinerator heat for the heating of digesters and the utilization of digester gas as an auxiliary fuel in the incinerator process. Additional interlocking may be obtained by the incineration of sewage screening and sewage sludge in the incinerator plant.

While this new type plant does not actually involve the combined disposal of sewage and garbage, it does indicate the tendency of municipalities to view these disposal processes as related municipal functions.

Plants of this type are in service at Canajoharie and Herkimer, N. Y., where the construction of these works have resulted in the winning of civic progress awards by the two communities. Similarly, a plant of this type is now in service at Dover, Delaware. A combined sewage-refuse disposal plant is also under construction at Lansing, Mich., and Winfield, Kansas. It is highly probable that additional plants of this type are now under construction or in service, as the trend toward this mutual-type plant seems to increase in the favor of both designing engineers and municipalities.

Are We Heading for Trouble?

In the face of these interesting trends in sewage-garbage disposal, the conservative sanitary engineer may well ask the question: "Are we heading for trouble in our desire to combine two municipal functions?" It was my intention at the outset of this rambling presentation to review the basic concepts that would quiet the fears of those who seem to doubt the ability of sewage plants to "take it." However, the proof of the pudding is in the eating, rather than in the theory that certain ingredients put together in the form of a pudding should taste good.

Viewed in this light, it is gratifying to report that practical development of the combined processes have been guided and checked by an active research program. Perhaps no trend in recent times has evoked such broad-gaged research. Investigators have checked the many phases of the problem which must be carefully checked before wide-scale adoption can be expected. There are many basic questions to be

answered—among them being: Can normal garbage be ground to consistency of sewage solids? Will pulped garbage or fresh wastes flow successfully through sewers? Will the material cause odors in sewers, and at sewage treatment plants? Will the material settle readily in clarification devices? Will the settled solids digest into a suitable sludge? What will be the effect on gas yields? Will the sludge be easily de-watered? Will the settled liquor be treatable in secondary devices? Can the treated effluent be as suitable for dilution as present-day effluent? These questions and many others naturally present themselves to the minds of sanitary engineers.

It is gratifying that many of these questions are today being investigated and that a number of them have been answered to the satisfaction of investigators. As an example of the unending search for knowledge, New York University has demonstrated the digestibility of sewage-garbage mixtures. Cornell University has demonstrated the digestibility of sewage and garbage mixtures. The University of Illinois has demonstrated the digestibility of sewage-garbage mixtures.

The New Jersey Sewage Experiment Station has recently demonstrated the digestibility of sewage and garbage, the settleability of mixtures of sewage and garbage, the ability of chemical precipitation methods to clarify the new wastes, the ability of mixtures of sewage and garbage to be de-watered, and the ability of mixtures of sewage and garbage to be oxidized in present-day sewage oxidation devices.

The Lawrence Experiment Station of the Massachusetts State Health Department has proven the treatability of mixtures of sewage and garbage in Imhoff and septic tanks. Harvard University has conducted studies on the rate of digestion of sewage-garbage mixtures.

In such municipalities as Indianapolis, Baltimore, and Schenectady, laboratory scale and practical scale investigations have shown the ability of sewage and prepared garbage to blend into a new type sewage which can be treated.

There are questions of treatment procedure involved, to be sure, but it is significant that none of the investigations disclose that the combined disposal of sewage and garbage is open to difficulties which can not be solved by the same type of intelligence and perseverance which has characterized the profession during the past decade of inspiring progress.

We watch with interest the engineers' first wholesale endeavor to modify the composition of sewage and to make sewage and garbage disposal related municipal functions. Sewage is the waste of life and living. In its pearly ripples we see sharp evidences of the food which makes life possible. That same life produces a waste called garbage. The materials of a waste-food nature flowing in sewage are akin to the wastes which today find their way into other channels of disposal. It is no far stretch of the imagination to view these two disposal problems as one related function of the municipality. If the blending of these two functions will result in the strengthening of each, then the engineer, by his interest in this reasonable interweaving of services, may be further aiding humanity.

CHEMICAL TREATMENT OF SEWAGE*

By Philip B. Streander

Consulting Engineer, New York City

That chemical treatment of sewage is of much interest is indicated by the fact that this meeting is being held in Elmira where there has just been placed in operation a rather unique and complete chemical treatment plant; a plant that during periods of low river flow will utilize chemical treatment and mechanical filtration and during the balance of the year will act as a plain settling plant—mechanical dewatering and incineration of the derived sludge being used for both methods of treatment. This flexibility in operation undoubtedly accounts largely for the success of this method of treatment. In addition to this flexibility in treatment results, another factor which undoubtedly has influenced the adoption of chemical treatment is the effectiveness of iron salts in the elimination of plant odor nuisance. This factor alone, has saved and will undoubtedly continue to save considerable sums of money by the elimination of long outfall sewers.

Chemical treatment of sewage has been widely discussed by many competent observers and writers and but little, except general comments, can be added to such writings and discussions. At the present time there are some forty plants in this country using this method of treatment. Undoubtedly it fills in a long needed gap between the results secured by primary treatment or plain settling and the much more expensive biological processes; and municipalities can now turn into the receiving waters a sewage effluent more consistent with the actual dilution requirements than was previously possible. Chemical treatment also serves to provide a means of preparatory treatment ahead of biological units, prolonging the life of such units which would otherwise be overloaded. It can also be economically applied to the treatment of industrial wastes either as complete treatment, where conditions allow, or as preliminary to final treatment. It is also quite useful in the treatment of municipal sewages containing large volumes of industrial wastes, which it might be impossible to treat properly in biological units. In fact, its application is so wide and its flexibility so great that installations may be made which are economically inadvisable.

Another factor in the widespread use of chemical treatment is the appearance of the plant effluent, particularly from the layman's viewpoint. Sewage treatment is not a popular subject with the public or its government, but there have been instances where interested city officials have spent much time in promoting the construction of sewage treatment plants. Of course where biological treatment is used these men can see actual results, but in most instances where only plain

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settling is provided they can not discern any difference between the sewage flowing in and that flowing out; so after having used their efforts and spent the public's money they are often extremely disappointed in what can be observed. From a psychological viewpoint therefore chemical treatment may gain adherents, particularly where the capital cost of the plant may be but a little higher than for plain settling.

Chemical treatment does not, however, have universal application. The treatment results secured are essentially the rather complete removal of suspended and colloidal solids, but less complete reductions in biochemical oxygen demand. The oxygen demands of the soluble matter still remains in an amount practically equal to that of the untreated or raw sewage, indicating that chemical treatment has little or no effect on dissolved sewage solids or the oxygen demand of these soluble substances. Where lime and iron are used, however, at pH 9.0 to 9.5 and the effluent is chlorinated, the chloramines produced are powerful retarders of biological action in the stream into which the effluent is discharged. This in many instances is a great asset as it allows a greater reaeration benefit, that is, the reaeration keeps ahead of the deoxygenation by the organisms and allows the undecomposed solids to travel to greater dilutions before oxidation is nearly so far advanced as it otherwise would have been.

The foregoing comments cover generally the application of chemical treatment to sewage, either as a means of effecting the major removal of suspended solids or as an adjunct or part of more complete or biological treatment units. Much has been learned during the past several years from plant operation and research work, which if properly interpreted can do much to increase the efficiency of chemical treatment plants. However, even with this array of plants and research work, much must be done before definite facts can be presented covering each phase and part of chemical sewage treatment. In the following there is given a brief outline of and comments on the component parts of chemical treatment.

Coagulation of Sewage Solids

Sewage is in itself an extremely complex agglomeration of biochemical substances, and this added to the other factors may at times give treatment results entirely at variance with other published and known results. Therefore unrelated results should not be compared and to determine the comparative efficiency of various methods, coincident and simultaneous tests should be conducted.

In the chemical treatment of sewage probably the factor of most interest is the degree of removal of the sewage solids. Sewage solids can be roughly divided into three main groups, namely: (1) settleable, (2) colloidal, and (3) dissolved. Chemical treatment deals chiefly with colloidal matter, as the efficiency of this method of treatment is due mainly to the coagulating effect on the colloidal solids.

Chemical treatment of all sewages is influenced by such factors as (1) the pH at which flocculation takes place; (2) the time of mixing; (3) the return and mixing of previously flocculated sewage with the raw sewage; (4) the effect of pre-settling of the sewage; (5) the return of sludge; and many other minor factors which may be troublesome at times.

In a review of the literature it is the consensus of those who have studied flocculation that optimum clarification occurs in two zones or pH ranges, between 2.5 to 3.5 on the acid side and between 9.0 to 10.5 on the alkaline side. Rudolfs states that the maximum removals of suspended solids is greater in the acid than in the alkaline range but that coagulation of stale sewage, containing large quantities of finely divided solids, is probably accomplished most successfully in the alkaline range. In connection with this it must be borne in mind that various sewages have variable isoelectric points or optimum pH conditions and dosages used for the flocculation of one sewage may be entirely inadequate or improper for treatment in another locality. Recent conceptions of the role of colloids place great stress upon pH determinations and pH maintenance at fixed values. Such conceptions may be proper, but are entirely localized and the results may not be applicable to other plants. Good judgment must be used in drawing conclusions from pH determinations.

Minute particles of insoluble substances are formed immediately following the introduction of the coagulating chemicals. These minute particles are not capable of crystallizing so that the growth of these flocs must be obtained by aggregation of the minute particles and such action is brought about by an external source such as mixing or agitation. The time required for the mixing of chemicals with the sewage depends somewhat on the characteristics of the sewage and the kind and amounts of chemicals used. Rudolfs in his experiments on chemical flocculation concludes that complete flocculation can be accomplished in from 15 to 30 minutes. Experiments by Link Belt Company, using laboratory models, indicated that complete mixing and flocculation can be accomplished in a much shorter period. Dallyn, of Toronto, in experiments made about five years ago found that mixing periods in excess of one hour gave the best results. In the Guggenheim types of plants long mixing periods have also been found best. With flocculation by means of air agitation, longer detention periods should serve to increase materially the dissolved oxygen in the sewage, to reduce the amounts of chemicals needed for equivalent results and in general to increase the efficiency of chemical treatment.

The return of chemical floc and the mixing of this with the chemically treated raw sewage is a factor on which but little experimental work has been done so that any comments made must of necessity be confined to generalities. It is known that the rate of floc formation is increased by an increase in the number of particles in a given volume of sewage, due to the increased probability that more particles will come together during mixing. The return of previously formed floc

and the mixing of this with the raw sewage should serve to increase the efficiency of floc formation, as there is an increase in the floc surface per unit of volume and there is therefore more area on which to build up the newly forming floc. Another possible advantage in the return of previously flocculated sewage is that in the first operation the higher forms or sizes of solids are agglutinated. On returning these and dispersing them through the incoming chemically treated sewage the finer forms or sizes of colloids have a nucleus on which to build newly forming floc.

Pre-settling of raw sewage is a procedure with which it was hoped that the amounts of coagulating chemicals could be reduced, because of the removal of the settleable solids from the raw sewage. In this connection, Rudolfs found that pre-settling of sewage does not appear to be of importance for clarification with an average quantity of suspended solids, in respect to the chemical demand. However, pre-settling may be beneficial with a sewage having unusually high amounts of suspended solids or when lime is used in conjunction with an iron salt. Pre-settlement or pre-treatment should provide a more uniform load on the coagulating unit of the treatment plant as it tends to reduce the wide variation in suspended solids content of the raw sewage. However, this phase of chemical treatment has not been developed to the point where it can be definitely stated whether or not it is beneficial in results or increases the efficiency of treatment.

The return of a portion of previously settled chemical sludge and mixing it with the chemically treated raw sewage has from the inception of chemical treatment been considered an aid to clarification. To what extent this is an aid is not definitely known, although it is generally conceded that the returned sludges have a definite clarifying value but that the same effect can be obtained with additional chemical dosage. Chemical sludge return to the entering raw sewage has been practised to some extent, but until it is more widely used and reported on, its value in chemical treatment results must remain a rather open question.

Settling of Flocculated Sewage

Detention of flocculated sewage under quiescent conditions is an essential and component part of the chemical treatment of sewage. The role played by settling is somewhat comparable to that of the settling of coagulated water, excepting that much larger amounts of solids must be precipitated. It should not be directly compared to the settling of raw sewage, because with chemical treatment the colloidal solids have been coagulated into forms which settle with comparative rapidity. Long detention periods are of no particular benefit, as it has been shown that satisfactory removals can be secured with periods as low as one hour. The form of the tank has some influence on its settling efficiency, rectangular tanks being probably most suitable for small plants and circular, radial flow preferable for the larger plants. This, however, is not set forth as a definite conclusion as it may be

varied by other considerations. Mechanical removal of the deposited sludge is of course an essential part of the settling tank.

Filtration of Settled Sewage

Mechanically cleaned filters should form an integral part of all chemical treatment plants as final filtration is quite essential for economical plant operation. It is difficult to compute the value of filtration as the actual amount of treatment or sewage purification is seldom clearly defined. While it may be true that the suspended and a major portion of the colloidal solids can be removed by settling, such removal can only be accomplished with perfect flocculation and most efficient settling. Even under these conditions it is practically impossible to remove the more finely divided floc without unduly high chemical costs.

The filtering of chemical treatment plant effluents offers advantages which are difficult to evaluate, such as the improved appearance of the effluent, more uniform treatment results and elimination of secondary deposits in the receiving water. Savings in chemicals can also be effected by the inclusion of mechanical filters, when compared on the basis of equivalent results. In plants where the chemical dosage is less than that required to secure a clean-cut break in the floc formation and a clear effluent upon settling, mechanical filtration will remove the major portion of the improperly coagulated solids. The combination of split flocculation and mechanical filtration should be of considerable economic value as in the final analysis whatever method, or combination of methods, produces the highest effect at the lowest cost, per unit of purification effected, is the most serviceable and practical scheme to pursue.

The form of filter bed to be provided is a matter more or less dependent on the design and arrangement of the plant. Where plant head is limited by natural conditions or where the sewage is pumped, the loss of head through the filter should be kept at a minimum. However, most plants are located above normal flood levels so that during most of the year there is available considerably more head than is indicated by the plant design. Advantage should be taken of such increased heads, as it is evident that the amount of wash water used will be decreased by increased final loss of head as the periods between washings, or lengths of run, are increased. Further, it is known that the real work of filtration is not that secured by flowing through the direct filter medium but rather by the added straining value secured by passing the liquid through the accumulated material retained on the filtering side of the filter media. Longer periods between washings will cause the retention of greater amounts of solids and thereby will increase the filtration efficiency. Filters having a depth of sand up to 30 inches have been successfully used for the filtration of sewages. While not directly advocating such depths it is believed that the trend in mechanical filtration will be toward deeper beds having a finer filter medium; using either the familiar back-wash arrangement used in

water plants or some form of mechanical cleaning. Deeper beds of finer material will provide more efficient filtration, thereby delivering a more highly polished effluent with possibly a saving in the cost of coagulating chemicals.

Disposal of Chemical Sludge

Sludge derived from the chemical treatment of sewage is naturally more voluminous than that from plain settling, due principally to higher removals of sewage solids and to the inclusion of the precipitated chemicals in the sludge. Its treatment and disposal does not, however, present any insurmountable difficulties as in the plants constructed up to the present time the sludge has actually been treated and removed.

In chemical treatment plants where the sewage is flocculated at a low pH, or on the acid side, digestion of the sludge is a practical method of reducing the putrescible solids to a comparatively innocuous sludge and drying this on sand bends or in mechanical sludge dewatering devices. Digestion of the sludge can be effected in the usual type of digestion units. Sludge gas can be collected and utilized for the maintenance of optimum digestion temperature and in the production of power in gas engine units. Lime and iron sludge produced at a comparatively high pH, 9.0 to 10.5, is not particularly amenable to digestion unless it is subjected to previous treatment.

Another method of sludge disposal consists of the dewatering of the raw sludge by mechanical means, followed by incineration of the dewatered product. Such a method produces an innocuous ash which can be readily disposed of and solves once and for all the problem of ultimate sludge disposal. Certain forms of incinerators are so designed that incineration may be optional and only drying may be effected. Such an arrangement makes it possible to utilize the dried sludge seasonally for application to lawns, parks, etc., and at other times the sludge is incinerated, producing an innocuous ash having about one-third the weight of the sewage solids, dry basis, entering the plant. However the use of chemical sludge as a fertilizer or soil conditioning agency has not from past performance been indicated as being of any value. In fact, experiences in other countries have indicated that farmers refuse to use such a sludge. Such refusal can be readily appreciated when it is considered that chemical sludge contains comparatively large amounts of lime and iron compounds; iron can not be considered as a suitable fertilizer, in fact, it has a deleterious effect on growths. Incineration of chemical sludge is therefore considered to be the logical method of disposal of the sludge derived from chemical treatment, at least from information and data now available.

In practically all chemical treatment plants where incineration has been provided, vacuum filters are used for sludge dewatering. These devices give consistently good results, delivering a sludge cake having a moisture content of between 60 and 70 per cent. In connection with

sludge dewatering it would be of considerable interest to observe the results which might be secured with centrifuges, because the characteristics of chemical sludge appear quite suitable for centrifugal dewatering. Various forms of dryers and incinerators are and will be available for the pre-drying and incineration of sewage sludges. At the present time practically the only form of incinerator installed in chemical treatment plants is the vertical multi-hearth, mechanically rabbled type, which appears to give consistently good results.

Treatment of Sewage and Garbage Mixtures

Considerable interest has been aroused in the grinding and discharge of garbage to the sewage either in the home, at centralized locations or at the site of the plant. The amount of added solids to be handled with complete grinding is approximately equal to the suspended solids ordinarily contained in the sewage on a dry basis. Such an addition will naturally place an additional load on the sewage treatment plant and chemical treatment may well be used as a means of reducing the load on supplementary biological treatment, or where dilution conditions so warrant, it may be the sole means of treatment. It is therefore of interest to consider what effect the inclusion of ground garbage may have on the form and on the results to be obtained in chemical treatment plants.

The addition of garbage solids to the sewage changes the characteristics of the mixture. Not only are the suspended solids almost doubled, but the dissolved solids are materially increased and as chemical treatment has but little effect on the dissolved solids, the B.O.D. of the effluent is greatly increased. In coagulation the mixture of garbage and sewage solids show generally the same characteristic as plain sewage, in that optimum clarification occurs in two zones or pH ranges. In the treatment of the mixtures it is considered that probably best results will be secured by operation at a high pH using lime and iron, using air mixing for flocculation and longer detention periods than for plain sewage. More grease and ether-soluble matter will accrue, due to the high grease content of the garbage, and means will have to be provided for its handling.

The results to be secured with pre-settling are problematical, but settling tank detention periods can be about the same as for plain sewage as ground garbage particles settle rapidly. Mechanical filtration of the effluent should also be provided, probably using deeper beds and a comparatively fine filter media so as to remove all trace of suspended solids. It may be possible to use higher chlorine dosages to cause some fixation of the dissolved organic matter and obtain a greater reaeration benefit and reduced deoxygenation.

More attention will have to be given to the disposal of the mixture of sewage and garbage solids. Greater peak loads will occur, as most of the garbage solids will be discharged during the day periods. Work carried on by various experimenters has indicated that the mixture

can be handled in digestion tanks under conditions similar to the digestion of plain sludge, excepting for the requirement of larger units to handle the increased volatile solids. Where mechanical dewatering and incineration will be provided as the means of disposal, vacuum filters will undoubtedly be continued. However, it is believed that in plants of this kind centrifugal dewatering may offer a number of advantages over vacuum filters as the sludge mixture should separate quickly from the liquid. Incineration will probably follow its present trend, but the sludge cake mixture will dry more readily and certain economies may be effected in the pre-drying of the sludge. Should all of the garbage be ground there remains the collection and disposal of the rubbish, the destruction of which can be combined with the combustion part of the incinerator providing thereby additional heat for the destruction of the garbage and sewage mixture.

Elmira Chemical Treatment Plant

As this meeting is being held at Elmira, more or less for the purpose of affording an inspection of this plant, there is given herein several salient features of the plant. It is designed to serve a population of 55,000 with an estimated dry weather flow of 5.5 M.G.D. Sewage from the city is carried by an intercepting sewer to the plant and is discharged into two circular, self-cleaning pump suction wells, ahead of which there is an automatic regulator which limits the rate of maximum flow to the plant. The pumps discharge into two flocculating chambers provided with horizontal rotary agitators and having a detention period of 15 minutes. From here it flows into two combined settling and filtration tanks having a detention period of 2 hours and equipped with Link-Belt sludge collectors and Laughlin automatically cleaned, upward flow, magnetite filters operating at a rate of 2 gallons per square foot per minute. The effluent from the filter flume flows into two circular, tangential flow chlorine contact tanks providing a detention period of 15 minutes.

When operating as a chemical treatment plant, lime is used for pH control and fed by means of a dry feed machine and lime slaking box, and ferric chloride is used as the coagulating agent. Both of these feeds are automatically controlled from the venturi tube and are arranged to feed chemicals at pre-determined rates proportional to the rate of flow. Settled sludge is pumped from the clarifiers into two sludge conditioning tanks, after which it flows to two 8 foot diameter by 8 foot long Conkey vacuum filters. The dewatered sludge or cake is carried on a belt conveyor to a vertical multi-hearth, mechanically rabbled combined dryer and incinerator of the Nichols-Herreshoff type. The incinerator is so designed that when required the sludge can be dried and used for fertilizing or soil conditioning purposes.

The design of this plant indicates the flexibility which can be provided by chemical treatment of sewage. The watershed of the Chemung River, into which the effluent is discharged, is inclined to be

"flashy" having rather extreme variations in dry and wet weather flows. During the periods of low river flow, particularly from May to October, the plant will use chemical treatment, delivering an effluent practically free of suspended solids and having a B.O.D. of 30 to 50 p.p.m. During the balance of the year, when the flow in the river is materially higher than summer flow, the plant will be operated on the basis of plain settling followed by mechanical filtration, reducing the suspended solids by between 60 and 65 per cent and the B.O.D. by a lesser amount. Under such conditions the plant effluent can be made to conform almost directly with the requirements of the river dilution. It is a plant that can be operated in comparative proximity to residential sections without creating a nuisance and in this installation this factor caused a material saving in the cost of the project in the elimination of a long outfall sewer which would undoubtedly have been required had some other method of treatment been provided.

Conclusion

Much has been accomplished in the past four or five years in the development of chemical treatment of sewage, particularly in the studies of various methods of flocculation, time of mixing, forms of mixing devices and the determination of the actual role of chemical treatment in the sewage disposal field. Considerable sums of money have been spent in development work not only by private interests, but also by individual research sponsored by public funds. It has been placed on a workable basis far removed from the uncertainty of the claims made in many of the allowed process patents and the claims made for the use of admixtures previously proposed have been largely discounted. Future developments in chemical treatment will undoubtedly be along the line of added refinements to the process and more economy in operation due to building of plants scientifically designed and more efficiently operated. It is believed that plants can be condensed into a smaller space and located at sites best serving the needs of the particular sewage system without creating a nuisance.

DEVELOPMENTS IN SEWAGE SLUDGE INCINERATION *

By Mark B. Owen

Vice President, Nichols Engineering and Research Corporation, 40 Wall Street, New York, N. Y.

This paper is not intended to be a complete story of the developments of sludge incineration generally, but will cover only those advances and installations of which the writer has first-hand information.

There are now some twenty-one sludge incinerator plants built, building or under contract. Of this number, I can safely discuss eighteen.

Dearborn.—The first successful sewage sludge incinerator, handling the total output of a full size treatment plant, was installed in the West Side Plant at Dearborn, Michigan, during the latter part of 1934.

Sludge incineration was decided upon for that plant when the first treatment works plans were drawn in 1931. Space was provided for an incinerator in the final plans of 1932, and funds provided for the installation.

Since the Dearborn method of treating sewage was new, and never tried in a full sized plant, it was decided to postpone the incinerator installation until more information could be obtained regarding sludge quantities and characteristics. Delaying this installation also provided additional time to conduct further studies and experiments of incineration.

Rather large sized test runs were made, burning Dearborn sludge in at least three types of incinerator equipment.

The unit actually and finally installed at Dearborn is a 16 ft. 9 in. diameter 6-hearth, mechanically rabbled, Nichols Herreshoff incinerator. This was placed in operation in January, 1935, and since that time every pound of sludge produced at both the East Side and West Side Plants has been burned in this unit. At no time since this installation has it been necessary to by-pass, or haul away sludge, because of any break-down of incinerator equipment.

There has been some misunderstanding of sludge characteristics at Dearborn. Less than 25 per cent of the sludge burned is from chemical precipitation. The balance is produced by sedimentation in modified Imhoff tanks and varies in volatile content with the seasons. In the winter months, the volatile content may reach 55 per cent and in the summer it may drop as low as 39 per cent. It may be safely stated then, that the Dearborn sludge is practically well-digested.

Some data on the cost of operation may be of interest. A recent analysis of costs is not available, but one made early in 1937 covering the first two years of operation, follows:

* Presented Before the Canadian Institute of Sewage and Sanitation, London, Ontario, Oct. 21, 1937.

Character of Sludge

Moisture, per cent (cake)	65.6
Dry solids, per cent (cake)	34.4
Volatiles, dry solids, per cent	46.6
Ash, dry solids, per cent	53.4
CaO, per cent of dry solids	10.7
$FeCl_3$, per cent of dry solids	1.58
B.T.U. per lb. of combustibles	10,400

Operating Data

(Total of two years)

Filter cake, tons	23,005.45
Dry solids, tons	7,907.29
Water, tons	15,098.16
CaO, lb.	1,527,789
$FeCl_3$, lb.	250,052
Fuel oil for incineration, gal.	41,146
Fuel oil for shut-downs, gal.	28,348
Fuel oil, total gal.	69,494
Power, for incineration, k.w.h.	87,129
Power, for shut-downs, k.w.h.	22,744
Power, total k.w.h.	109,873
Hours operated	10,348.5
Equivalent days operated	431.16
Hours, shut-down	7,195.5
Equivalent days, shut-down	299.81
Rate of incineration:	
Tons filter cake per hour	2.22
Tons filter cake per day	53.28
Tons dry solids per hour	.764
Tons dry solids per day	18.336

Fuel Oil

For actual burning of sludge—2 yr. average:	
Per ton wet cake	1.79 gal.
Per ton dry solids	5.20 gal.
Per ton water	2.71 gal.
During shut-downs—2 yr. average:	
Per hour	3.94 gal.
Total—2 yr. average:	
Per ton cake	3.02 gal.
Per ton dry solids	9.38 gal.
Per ton water	4.60 gal.
Per hour per year	3.96 gal.

Operating Costs—2yr. Average for Incineration—per Ton Cake

Fuel	$0.075
Power	0.039
Maintenance	0.014
Labor	0.150
Total	$0.278
Including shut-downs	
Total	$0.381

Kokomo, Indiana.—The second incinerator of this type to be constructed was at Kokomo, Indiana, and this installation represents probably the first development in extending the usefulness of the furnace, as well as sewage plant itself. Mr. Russell B. Moore, the consulting engineer, specified that this unit be large enough to handle 7 tons of wet shredded garbage in addition to 6 tons of digested sewage sludge.

While this plant is now operating, provisions have not yet been made for handling garbage, other than in furnace capacity.

This plan appears to the writer to offer a most attractive means of economically disposing of two troublesome municipal wastes. In this particular plant, the addition of garbage will have a beneficial effect on fuel consumption. The sludge being digested will have lost much of its fuel value, so that the addition of garbage will actually increase the fuel value of material to be burned, and decrease the demand for extraneous fuel.

Just what plan the city may follow in feeding the shredded garbage to the furnace is not known at present. The writer would seriously consider, and has so recommended to others, the mixing of ground garbage with wet sludge prior to chemical conditioning and vacuum filtration. There is a possibility that this mixture may require less chemicals and may produce more pounds of filter cake per square foot of filter area.

The furnace at Kokomo is a 9 ft. 3 in. diameter 6-hearth unit. The feed is equivalent to 18.4 tons of material per 24 hours.

Kaukauna, Wisconsin.—The plant in this city is arranged to handle sewage sludge and ground garbage, but with one additional feature over those mentioned under Kokomo. Equipment for handling garbage is already installed in Kaukauna. Facilities are available for garbage grinding and conveying the milled material either directly to the furnace, or into a sludge sump ahead of the vacuum filters. The idea behind this plan seems to be that any peak volumes of garbage over and above the amount the filter might satisfactorily handle, can be disposed of direct to the furnace.

The writer understands that certain wastes from paper mills may also eventually be treated in this sewage plant. Industrial wastes may be more easily handled in municipal treatment plants where incineration is employed. If this be true, it is one example of the effect of incineration on plant design.

The basis of design contemplates that during ten months of the year, 8.33 tons of undigested sludge and ground garbage will be handled in six hours; and for two months, 33 1/3 tons of chemically precipitated sludge and ground garbage will be incinerated in 22 hours.

This furnace is 14 ft. 3 in. in diameter and has four hearths. The plant was designed by Greeley and Hansen.

Detroit, Michigan.—The largest single installation of sludge furnaces will soon be under way in Detroit. Four units, 22 ft. 3 in. in diameter and containing 12 hearths each, will be used to burn a maximum load of 1,320 tons of filter cake in 24 hours.

In this plant, another departure from other installations is the disposal of grit, shredded screenings and scum with the sludge. Here also, digestion was eliminated and all sludge burned will be that from plain sedimentation.

Disposing of grit by burning with sludge presents another feature affecting plant design.

The plant design was under Messrs. Hubbell, Eddy and Gregory by the staff of the City.

Other Plants.—Generally, the sewage of each municipality presents to the designing engineer some problem calling for an entirely different arrangement of one or more parts of the plant. Many times these special characteristics call for a special routine of plant operation.

In nearly every case studied by the writer, where these unusual conditions exist, incineration would make possible simplified design or operation, or both.

The plants already described happen to come within this category and listing them separately was for the purpose of indicating certain possibilities. The other sewage treatment plants referred to earlier in this paper are by no means standard in design, but represent some new idea, or development in the rapidly progressing field of sewage treatment.

In the latter group are plants at the following places: Auburn, N. Y.; Thompsonville, Conn.; La Porte, Ind.; Colorado Springs, Colo.; New Britain, Conn.; Middletown, Conn.; Elmira, N. Y.; Cleveland, O. (two 14 ft. 3 in. diameter 6-hearth units at the Westerly Plant, and four 18 ft. 9 in. diameter 8-hearth units at the Southerly Plant. Design by Mr. George B. Gascoigne and Associates); Minneapolis-St. Paul Sanitary District (three 22 ft. 3 in. diameter 8-hearth units); Greece, N. Y.; Conshohocken, Pa.; and Barberton, Ohio.

Effect of Incineration on Plant Design.—I have already indicated how incineration may affect plant design. A more explicit discussion may be of interest.

Basically, the whole idea behind sewage treatment is the separation of organic matter from the liquid, and ultimate disposal of the organic matter. Strangely enough, treatment processes are rated by their ability to remove these organics, with no consideration being given to the method of final disposal of the removed organic material.

Is it not possible that too much stress is placed on the quality of effluent, usually containing very small percentages of organic matter, and too little attention paid to sludge, that may contain very high quantities of putrescible organics and possibly pathogenic bacteria.

The writer has no desire at this time to open a lengthy discussion on the subject of the effect of sludge when used as a fertilizer—either as to its value in that respect, or the possible inherent danger to the health of the people. I do wish to make certain comments, however, and quote certain authorities who have given this subject much thought and study.

Referring again to the separation of organics from sewage, Dr. F.

W. Mohlman, Editor of the *Sewage Works Journal*, in an editorial in the September, 1933, issue, said:

The removal of bacteria is an important function of sewage treatment processes, but in recent years its importance as a measure of efficiency of sewage treatment has been overshadowed by interest in the removal or stabilization of organic matter by biological oxidation. This changed viewpoint has been brought about by the knowledge that chlorination is more effective and cheaper than biological oxidation as a means of removing bacteria.

To the layman or public health official, the removal of bacteria may seem to be the primary function of sewage treatment, and in cases where protection of water supplies, oyster beds or bathing beaches is required, bactericidal efficiency is paramount.

There are several factors which contribute to the diminution of infectivity of the bacteria in sewage. The first barrier to the escape is the treatment process, comprising, in complete treatment, oxidation, sedimentation and retention of the bacteria in sludge.

Dr. Fred W. Tanner, Professor of Bacteriology at the University of Illinois, presented a paper before the May, 1935, meeting of the Illinois Association of Sanitary Districts, and in his summary, stated:

The application of sewage sludge to soil on which vegetables which may be eaten raw are grown, should be practiced with caution. While results of longevity studies on pathogenic bacteria in sludge would probably be greatly influenced by the nature of the sludge and conditions under which it is stored and handled, sufficient data have been recorded to indicate the presence of viable *Bacterium typhosum* cells in sludge. . . . Sanitary districts and others concerned with the sale of sludge to farmers might well consider the possible health hazards involved.

In the November, 1929, issue of *Water Works and Sewerage*, appeared the following on The Editor's Page:

During the World War, patriotism included saving peach stones for gas mask carbon, saving our Sunday newspapers, and transforming garbage into hog meat and fat. But during that period most of the acts of our lives were abnormal; and because it was almost criminal then to burn garbage and sewage sludge, is no argument that such disposition of waste organic matters is not now permissible and even praiseworthy.

What is the proper disposition of waste organic matters should be decided solely on the basis of sanitation, convenience, dollars and sense—no idea of "conservation of resources" enters into the question. Anything found in garbage, from beans to beef, could be replaced in a year or two with very little effort—the destruction of it inflicts no hardship on the coming generations. Sewage sludge may provide good fertilizer base, but there are plenty of other matters available which are just as good.

The dollar consideration is of little more importance, although it seems difficult to make the taxpayers, or even their officials, realize it. If each individual in the country of movie-going age would cut out one movie a year, the saving would pay the entire cost of disposing of all the garbage of the country by any of the standard methods. And the country pays more for chewing gum than would be required to dispose of all its sewage by the most up-to-date methods, including oxidation and chlorination.

There remain then sanitation, convenience and sense, and the greatest of these is sense—"common sense"; so-called, some one has said, because it is the least common thing on earth.

If the above statements are not greatly exaggerated, common sense would seem to indicate that proper disposition of liquid and solid wastes requires the total destruction of all matters that may injure the health of any human beings, and in such way as will not give any offense to any of their senses. This having been assured, whatever profit can be made or reduction in expense effected is so much "velvet."

But conservation of resources and expense (other than waste of money), are the least considerations in solving the waste disposal problem.

While the above editorial appeared just eight years ago, it still might well be published today. It is of more importance today than eight years ago, because of the vast number of sewage plants in operation at the present time.

If incineration is employed as the means of solids disposal, the problem of destroying pathogenic bacteria and putrescible organic solids is quite definitely solved.

Therefore, the first effect on sewage plant design may be in grit collecting equipment. Where now great emphasis is placed on grit channel design to provide for settling of grits without deposition of organic matter, simpler structures are possible because all grit and related solids may be incinerated.

The present increasing use of screenings grinding equipment fits in well with incineration since ground screenings are easily burned and add considerable by way of fuel in an incinerator. They may be left in, or returned to, the sewage, or taken directly to the furnace after shredding.

Vacuum filtration of undigested sludge is now being practiced in enough plants to warrant the statement that it is now one of the standard methods. Therefore, where other considerations are not in the problem, no particular reason remains for digesting sludge as a means of reducing the organic content. On the contrary, raw sludge filters equally as well, or better than, digested and burns more readily. The question may be raised that digestion of sludge means a reduction in solids, and consequent reduction in the size of apparatus required for its disposal. The answer to that may be found in capitalizing the cost of structures and operating costs of both plans and comparing them.

Incineration equipment for handling raw sludge is decidedly more simple in design and operation, and the cost of operation per ton of sludge burned considerably less than that for digested sludge.

Since only some of the possible developments of incineration, and as a result of incineration, were to be covered by this paper, no mention will be made of the many other factors and features that generally will apply to every plant.

SEWAGE TREATMENT AT IOWA CITY, IOWA *

By Earle L. Waterman and Royal E. Rostenbach

Professor of Sanitary Engineering and Research Assistant in Sanitary Engineering
University of Iowa, Iowa City

Several interesting facts have been established by a study of a year's operating data obtained at the new sewage treatment plant in Iowa City, Iowa. First, the strength of the sewage treated was considerably greater than that anticipated from the preliminary investigations made prior to the design of the plant. Second, the efficiencies of both the primary and secondary units have been higher than might be expected from an investigation of results obtained at other plants. Third, the over-all plant efficiency has been remarkably uniform from month to month throughout the year. Not only was the efficiency, as measured by the 5-day B.O.D. removal, high, but the monthly averages varied less than 4 per cent from the yearly average.

Iowa City is characterized by the fact that it is the seat of the State University. The resident population is estimated to be 16,750. The University Hospital had an average non-resident population of 900 during the past year. Sewage from a small suburb, having a resident population of 250, is discharged into the city sewerage system. There is a student population of 6,000 during the college year. While there is some fluctuation in the contributing population at certain periods during the year, the authors believe that an average figure for the year would be 23,900. There are no industrial wastes other than those normally coming from milk plants and laundries in a city of this size.

Sewerage System

The original sewerage system which serves the older part of the city in the area east of the Iowa River was built as a combined system. The West Side system, built about ten years ago, is a separate system. When the sewerage improvements—which included the sewage treatment plant—were built in 1935, there was some further separation of storm water in the East Side system. Thus the sewage treated by the new plant is essentially domestic but often diluted by storm water. The plant was designed to take care of three times the dry weather flow.

The sewerage improvements are being financed by sewer rentals. The ordinance provides that service charges shall be on the basis of monthly water consumption and the strength of the sewage as determined by the average 5-day B.O.D. The different rates per 100 cu. ft. of water consumption are:

B.O.D., 0–100 p.p.m.	$0.03
B.O.D., 100–400 p.p.m.	$0.075
B.O.D., over 400 p.p.m.	$0.155

* Presented at the Iowa Sewage Treatment Conference, December 2, 1937.

In actual practice there are no charges being made at the higher rate. Domestic sewage is assumed to be in the second class. In some instances separate meters have been installed to measure water used in air conditioning and this is billed at the low rate. There have been a few investigations made to determine classification but in general there appears to be satisfaction with the arbitrary assignments.

However, there has been one unanticipated result of this method of charging for sewer service. A considerable quantity of water used for cooling purposes, which was formerly discharged into the city sewers, has now been diverted to storm drains. The average of five 24-hour composite samples, taken from the sewer outfalls prior to the construction of the sewage treatment plant, gave a 5-day B.O.D. of 233 p.p.m. The average 5-day B.O.D. of the raw sewage for the year ending September 30, 1937, has been 370 p.p.m. The reduction in sewage flow per capita has been approximately 20 per cent.

Sewage Treatment Plant

The general arrangement of the Iowa City Sewage treatment plant is shown in Fig. 1. It consists of a grit chamber, coarse screens, pump-

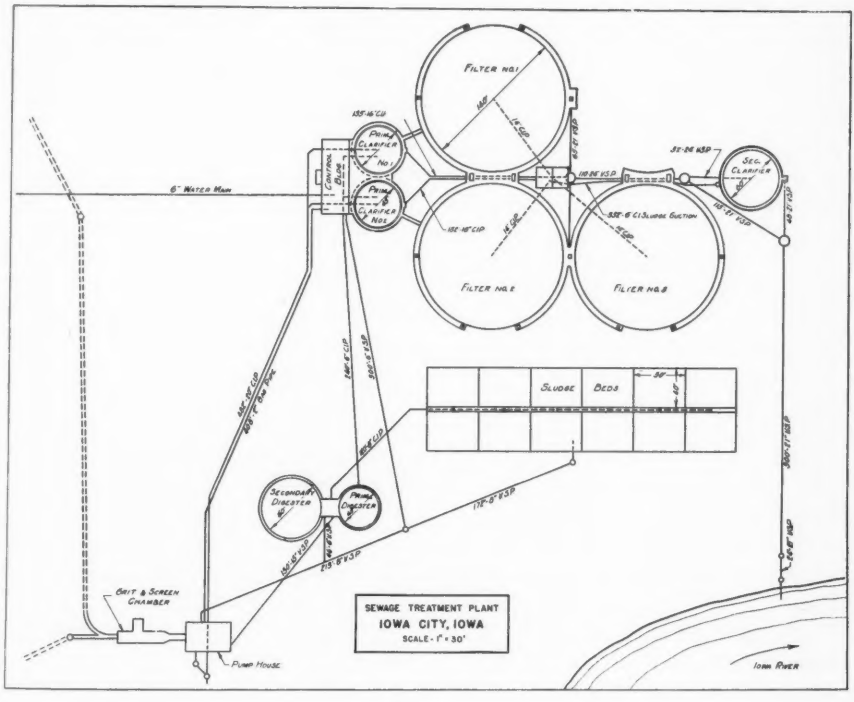

Fig. 1.

ing plant, control house, primary clarifiers, trickling filters, humus tank, primary and secondary digestion tanks and sludge beds.

Sewage passes through the grit chamber, where there is an average daily removal of 15.3 cu. ft. of grit, then through a mechanically cleaned bar screen to the wet well in the pump house. The ¾-in. clear opening screen retains about 4 cu. ft. of screenings per day. These are ground and returned to the sewage.

The pumping equipment consists of four pumps having capacities of 2, 3, 4 and 6 m.g.d. operating against a 27 ft. head. The pumps are automatically controlled through switches operated by floats in the wet well. Power requirements for pumping during the year averaged 189 K.W.H. per day with a maximum of 223 K.W.H. and a minimum of 167 K.W.H. These figures include all power used in the plant.

Control House.—A 20-in. cast-iron force main carries the sewage from the pumps to the control house. Here the flow is divided and passes through two Venturi meters to the primary clarifiers. The sludge pumps, building heating equipment, and a sump pump for the house drainage are located in the basement of the control building. The first floor is divided into a garage, entrance lobby, a work shop, a locker room, and a toilet room. Laboratory, offices, flow-recording mechanisms, and the electrical switch board which controls all power operations, are located on the second floor of the control house.

Clarifiers.—The primary clarifiers are of the Sifeed type. Sewage enters at the center of the circular basins and leaves over weirs around the periphery. Motor-operated scrapers move the settled sludge toward the center and also move a skimming device over the surface of the liquid. During the year the detention period in the clarifiers was 3.05 hours for the average flow during the maximum month.

At the average flow rate the flow through the clarifiers was 590 gal. per sq. ft. per day and the reduction in suspended solids was 54.4 per cent. For the maximum month the corresponding data were 734 gal. per sq. ft. per day and 52.5 per cent; minimum month—484 gal. and 58.5 per cent. It should be noted, however, that the flow through the clarifiers is variable depending upon the pump in operation. During the night hours flow is stopped about half the time.

Filters.—There are three units of trickling filters, each 140 ft. in diameter and filled with broken limestone to an average depth of 6 ft. 10 in. Settled sewage is applied to the filters by rotary distributors. The filter stone is a local limestone which was screened through a 2½ in. screen and retained on a 1½ in. screen. During the winter months only two filters are kept in operation.

Humus Tank.—The effluent from the filters passes through a humus tank, or secondary clarifier, of the same type as the primary clarifiers. This tank is 60 ft. in diameter with a side wall water depth of 7.5 ft. The detention period at the average flow rate for the year was 2.04 hours. The sludge collected in the humus tank flows by gravity to the wet well in the pump house.

Sludge Digestion.—Sludge from the primary clarifiers is pumped to the primary digestion tank. After partial digestion it is transferred to the secondary digestion tank and finally the digested sludge is air dried

on sludge beds. Both digesters are equipped with gas holder steel covers. The primary digester is heated by hot water circulating through pipe coils attached to the wall of the tank.

Gas collected from the digestion tanks is used for heating the primary digester, the control house, and the laboratory.

A commercial gas was used to heat the digester during the first few months of the plant operation. After digestion started there was a period of rather violent foaming which lasted through the first summer. The use of lime perhaps helped the situation but certainly did not control it. The digesters apparently reached a normal operating balance in September, 1936, and have given little trouble since.

During the foaming period some of the foam got into the gas line and ruined the master gas meter. It has not been re-set since it was returned from the factory. There are meters on the gas lines supplying the water heater in the pump house and the control building. Hence, while there is no record of the total quantity of gas produced, the quantity actually utilized is recorded.

The hot-water circulating coils in the primary digester were made of aluminum pipe. After about twenty months service these pipes failed and were replaced by wrought iron pipe. The failure was due to corrosion on the outside of the pipe. The cause has not yet been determined.

Operating Results

Laboratory control of the plant operation was not well established until September, 1936. This date also marks the beginning of normal plant operation. The monthly records have been summarized in the following tables to show what the plant did during the year ending October 1, 1937.

The average daily flows of sewage through the plant for each month, as shown in Table I, show the effect of two influencing factors. The first is the increased flow during months in which conditions were favorable for a maximum runoff of surface water—maximum flows were treated during February and March. The second factor is that of changing population. Low flows occurred during the months of August and September when the number of students in residence was at a minimum.

It is generally agreed that the most satisfactory yardstick to use in measuring the efficiency of sewage treatment is the reduction in biochemical oxygen demand. On this basis, as shown in Table I, the average efficiency of the primary clarifiers during the year was 47.3 per cent, that of the filters and humus tanks combined was 83.2 per cent, and that of the entire plant was 91.1 per cent.

One very interesting fact brought out by these data is the uniformity in the efficiency of both clarifiers and filters throughout the year. The variation from the average for both units is less than 6 per cent. This is quite unusual in a climate where the temperature ranges from 20 degrees below zero in the winter to 90 degrees above in the summer.

The suggestion is offered that the probable explanation will be found to be due to the improvements in clarifier design and to the reduced air exposure of sewage as it is applied to the filter surface.

Table II shows the quantity reductions in 5-day B.O.D. through the plant. These data are also shown graphically in Fig. 2. Further evidence of the efficient operation of the filters is given by the pounds of B.O.D. removed by the filters per acre-foot. This averaged 452 pounds for the year and during the winter months of January, February, and March the average filter performance per acre foot was 36 per cent above the yearly average. During February the load carried was 58 per cent greater than the yearly average.

TABLE I.—*Monthly Average, Biochemical Oxygen Demand Reductions Through Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Sewage Flow M.G.D.	5-day B.O.D. P.p.m.			Reduction of B.O.D. Per Cent		
		Raw Sewage	Clarifier Effluent	Plant Effluent	Clarifiers	Filters and Humus Tank	Plant
Oct.	1.73	406	223	31	45.4	86.2	92.4
Nov.	1.67	419	207	27	50.7	87.0	93.5
Dec.	1.67	407	229	48	43.7	79.1	87.4
Jan.	1.73	421	230	42	44.5	81.4	89.7
Feb.	2.33	393	209	34	46.8	83.8	91.5
Mar.	2.33	363	178	40	50.9	77.5	88.9
April	2.06	355	188	37	47.0	80.4	89.3
May	2.20	330	171	37	48.3	78.4	88.7
June	1.835	307	159	24	48.2	84.7	92.2
July	1.766	314	181	31	42.4	82.8	87.0
Aug.	1.607	377	188	26	50.2	86.2	93.4
Sept.	1.536	346	170	26	50.8	84.7	92.7
Max.	2.33	421	230	48	50.9	87.0	93.5
Avg.	1.87	370	195	33	47.3	83.2	91.1
Min.	1.536	307	159	26	42.4	77.5	87.4

Sewage treatment plant efficiencies may also be judged by the reduction in solids. Data showing this phase of the plant operation are presented in Table III. It will be noted the average reduction in total solids was from 960 to 615 p.p.m. or 36 per cent; the reduction in suspended solids was from 285 to 40 p.p.m., or 85 per cent.

Another important function of a sewage treatment plant is the digestion of the sludge which accumulates in the settling basins. Table IV shows the monthly averages for raw sludge and digester data. The figures on the quantity of dry solids added to the digester per day are believed to be about ten per cent high, for the reason that the quantity of sludge pumped was calculated upon the basis of 50 gallons per min-

TABLE II.—*Monthly Averages, Quantity Reductions in B.O.D. Through Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Sewage Flow M.G.D.	B.O.D. Removal per Day Pounds			Filter Data	
		By Clarifiers	By Filters and Humus Tank	By Entire Plant	Acre Ft. in Service	Lbs. B.O.D. Removed Per Acre Ft.
Oct.	1.73	2630	2770	5400	7.06	393
Nov.	1.67	2950	2500	5450	7.06	354
Dec.	1.67	2475	2520	4995	4.72	532
Jan.	1.73	2740	2700	5440	4.72	572
Feb.	2.33	3540	3375	6915	4.72	715
Mar.	2.33	3560	2650	6210	4.72	562
April	2.06	2880	2580	5460	7.06	365
May	2.20	2903	2300	5230	7.06	326
June	1.835	2187	2018	4205	4.72	427
July	1.766	1960	2197	4068	4.72	466
Aug.	1.607	2530	2160	4690	4.72	457
Sept.	1.536	2230	1840	4070	7.06	260
Max.	2.33	3560	3375	6915		715
Avg.	1.87	2715	2410	5110		452
Min.	1.536	1960	1840	4068		260

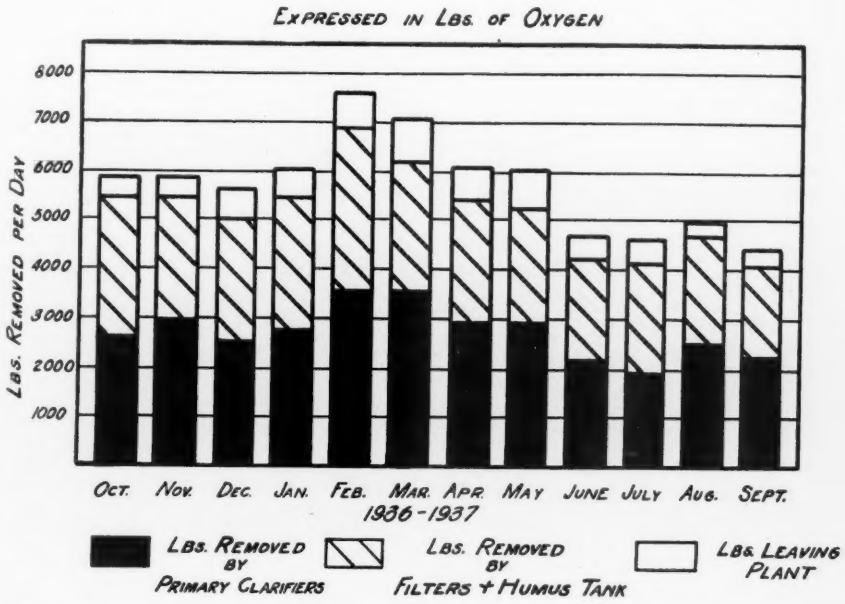

FIG. 2.—Daily monthly averages of 5-day B.O.D material removed expressed in lbs. of oxygen.

TABLE III.—*Monthly Averages, Reduction in Solids Through Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Raw Sewage				Clarifier Effluent				Plant Effluent			
	Total Solids P.p.m.		Susp. Solids P.p.m.		Total Solids P.p.m.		Susp. Solids P.p.m.		Total Solids P.p.m.		Susp. Solids P.p.m.	
	Total	Vol.	Total	Vol.	Total	Vol.	Total	Vol.	Total	Vol.	Total	Vol.
Oct.	888	541	219	102	698	306	83	36	530	156	17	3
Nov.	907	537	280	113	688	328	103	42	561	196	27	3
Dec.	1020	560	354	198	760	360	152	62	630	240	45	11
Jan.	953	501	303	207	743	348	155	95	660	242	60	28
Feb.	870	505	295	185	669	385	170	90	576	230	59	16
Mar.	921	529	305	152	682	420	143	67	594	301	113	45
April	917	553	325	164	717	413	216	100	560	333	30	9
May	1059	505	338	164	730	345	124	74	591	269	24	8
June	1113	423	254	149	803	290	96	77	727	227	15	6
July	953	364	226	168	748	256	107	77	584	199	18	13
Aug.	892	360	248	163	648	233	109	75	717	249	19	10
Sept.	1000	430	277	192	800	305	115	78	664	230	28	17
Max.	1113	560	354	207	803	420	216	100	727	333	113	45
Avg.	960	485	285	165	725	330	130	75	615	240	40	15
Min.	870	360	219	102	648	233	83	36	530	156	15	3

TABLE IV.—*Monthly Averages, Raw Sludge and Digester Data, Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Raw Sludge			Digester Data			
	Thousands Lbs. Dry Solids to Digester per Day	Per Cent Dry Solids	Per Cent Volatile Matter	Temperature Degrees F.		pH	
				Primary	Secondary	Primary	Secondary
Oct.	15.3*	9.4	49.4	74	—	—	—
Nov.	4.18	6.4	64.5	79	—	—	—
Dec.	6.50	6.43	63.5	82	62	7.0	7.0
Jan.	5.21	6.21	64.4	80	60	7.2	7.1
Feb	6.25	6.6	63.5	78	60	7.3	—
Mar.	8.50	11.3	44.2	78	60	7.2	7.2
April	7.60	8.9	50.7	81	64	7.2	7.2
May	7.47	8.05	45.6	85	72	7.2	7.2
June	5.53	6.8	51.8	89	78	7.2	7.2
July	6.01	6.4	54.7	92	84	7.2	7.2
Aug.	5.38	6.0	59.0	90	86	7.1	7.2
Sept.	4.64	4.8	62.5	91	83	7.0	7.1
Max.	8.50	11.3	64.5	92	86		
Avg.	6.12	7.27	56.1	83	71		
Min.	4.18	4.8	44.2	74	60		

* Not included in average.

ute capacity of the sludge pumps. A recent investigation developed the fact that the pumps are operating at about 45 g.p.m.

Even this correction did not reconcile an apparent discrepancy between the quantity of suspended solids removed by the primary clarifiers and quantity of solids added to the digester. Clarifier performance as determined by our sampling stations does not include the suspended solids added to the wet well by the sludge from the humus tank and the ground screenings. Assuming an average population of 23,900, the average quantity of dry solids added to the digester per day is 0.256 pounds per capita. On the basis of average reduction in total solids through the clarifier the amount of dry solids in the clarifier sludge is only 0.153 pound per capita per day and the conclusion is reached that about 0.10 pound per capita per day of dry solids is collected in humus tank.

The composition and heat values of the gas collected from the digesters and the quantities used for different purposes are set forth as monthly averages in Table V. An examination of the figures showing

TABLE V.—*Gas Data, Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Composition, Per Cent			B.T.U. per Cubic Ft.	Gas Used Per Day, Cu. Ft.		
	CO_2	H_2	CH_4		Heating Digester	Control House	Total
Oct.	26.2	26.4	44.4	538	—	—	—
Nov.	28.4	18.8	48.4	545	7187	3227	10,414
Dec.	30.4	9.9	48.1	514	8110	5736	12,736
Jan.	32.0	10.7	48.9	527	8500	6274	14,794
Feb.	31.4	15.2	50.8	560	8550	4900	13,450
Mar.	31.0	13.0	51.8	561	7500	4880	12,300
April	30.5	6.2	59.2	614	7227	5500	12,727
May	31.7	4.6	61.4	629	6745	1106	7,851
June	32.2	4.0	60.7	620	5830	207	6,037
July	32.2	3.7	62.5	637	4474	113	4,587
Aug.	32.5	4.0	63.0	641	3858	129	3,980
Sept.	32.1	5.1	61.5	633	5627	733	6,360
Max.	32.5	26.4	63.0	641	8550	6274	14,794
Avg.	30.9	10.1	55.0	585	6691	2982	9,567
Min.	26.2	3.7	44.4	514	3858	113	3,980

the composition of the gas shows that the digesters did not attain a normal balance until last April. The percentages of carbon dioxide, hydrogen, and methane as well as the B.T.U.'s per cu. ft. have been quite consistent since that time. The fact that these values are somewhat lower than values reported elsewhere may perhaps be attributed to the fact that the sewage is somewhat diluted by storm water.

Table VI shows data on grit, screenings, and power. The figures on power include power used for all purposes in plant operation

TABLE VI.—*Monthly Averages, Grit-Screenings-Power Sewage Treatment Plant, Iowa City, Iowa*

Month 1936 1937	Grit, Cubic Feet per Day	Screenings, Cubic Feet per Day	Power K.W.H.		Light, K.W.H. per Day	Plant, Total K.W.H. per Day
			Total per Day	Per M.G.D.		
Oct.	16.0	8.0	335	193.5	21	356
Nov.	7.7	6.4	310	185.5	18	328
Dec.	8.6	6.2	303	183.5	16	319
Jan.	7.3	3.7	348	199.5	17	365
Feb.	15.6	4.4	412	176.5	17	429
Mar.	33.4	10.0	390	167.0	14	404
April	12.1	5.7	362	175.8	18	380
May	23.6	4.4	372	170.1	14	387
June	15.5	4.2	337	183.5	13	349
July	16.4	4.2	356	202	13	369
Aug.	13.2	3.5	331	210	14	345
Sept.	14.7	4.8	343	223	15	358
Max.	33.4	10.0	412	223	21	429
Avg.	15.3	4.7	350	189	16	366
Min.	7.3	3.5	303	167	13	319

through eighteen different motors. The largest demand is for pumping.

The Iowa City sewage treatment plant was designed by the Currie Engineering Company. The cost of the plant was $285,000. Mr. F. W. Louis was superintendent of plant operation until April, 1937. Mr. J. F. Sproatt has held the position since that date. The authors are indebted to these gentlemen for their courtesy in making plant records available for this study.

Industrial Wastes

PRACTICAL METHODS OF PREVENTING DAIRY WASTE NUISANCE *

By Charles C. Agar

Senior Sanitary Engineer,
New York State Department of Health, Albany

Nuisances caused by improper disposal of dairy wastes are probably the most common industrial waste problems confronting health authorities today. The liquid wastes, including wash water from cans, equipment and floors, spilled milk, whey, buttermilk, skim-milk, etc., which are discharged into small streams or drainage ditches, invariably result in objectionable and insanitary conditions. The stream becomes unsightly, decomposition proceeds rapidly, sludge deposits are formed, obnoxious odors are produced, dissolved oxygen in the stream is depleted and fish and normal aquatic life are destroyed. When such wastes are discharged into the municipal sewer system, particularly in the smaller municipalities, operation of the sewage treatment plant is usually disrupted. Odors are produced, sludge becomes acid, retarding digestion, and secondary treatment units such as sand filters and trickling filters become fouled. The quality of the effluent is seriously impaired and the receiving watercourse becomes excessively polluted.

There is an increasing public demand for clean streams and the control of all types of pollution. This attitude is reflected in the increasing number of complaints of stream pollution received by health and conservation authorities each year. But there are added reasons for the unusual gravity of nuisance problems involving the disposal of milk. Time was when milk plants were located at nearly every crossroads. This was necessarily so in the days of horse-drawn vehicles but with modern motorized equipment we find most of the small milk plants abandoned and a continuing concentration and centralization of the activities of the milk industry at large plants. Too often, due consideration has not been given to the location of these plants with respect to disposal of wastes. The volume of wastes necessarily increases almost in direct proportion to the quantity of milk being received. Doubtless there were many localized conditions of nuisance from the wastes of the small plants but with the present concentration of activities the problems of waste disposal are increased many fold.

May I at the outset state that I believe the milk industry is fully cognizant of the milk waste problems and is able and willing to co-

* Presented at the Joint Session of the American Public Health Association and the New York State Sewage Works Association, New York City, October 8, 1937.

operate in their study and solution. Much commendable work has already been undertaken and a number of satisfactory milk waste treatment plants are in operation today. Unfortunately, however, the wastes from most plants are untreated and at many plants where some measure of treatment is provided the treatment works are inadequate and obsolete.

Milk is primarily an aqueous solution of milk sugar, mineral salts and soluble albumin and contains suspended globules of fat and partially dissolved casein. The solids in milk, amounting to approximately 13 per cent by weight, are preponderantly organic and contain only a relatively small amount of inorganic mineral salts. The solids in milk, such as milk sugar or lactose, are unstable and readily decomposable under the influence of bacteria or biological action. This accounts for the rapidity with which changes occur in milk or milk wastes upon standing, unless special precautions are taken.

In order to understand the potency of milk and milk wastes as a cause of nuisances, let us compare the strength of domestic sewage with milk and its various wastes. The solid content of an average domestic sewage is about 800 p.p.m., being higher or lower according to the total solid content of the water supply. The volatile or organic solids of such sewage, which are more nearly a criterion of its nuisance producing power, amount to about 400 p.p.m. These figures in themselves mean little but when compared with the solids in milk or dairy wastes they become significant. The total solids in whole milk amount to about 130,000 p.p.m., of which 123,000 p.p.m. are organic. Milk, therefore, contains over 300 times as much organic matter as sewage. Now let us consider milk wastes such as those from a milk receiving station, where they consist only of washings from cans, floors, equipment, etc. The normal milk solids content in such wastes frequently amounts to approximately 1,300 p.p.m., of which 1,230 p.p.m. are organic. There is, therefore, several times the organic solids content in milk wastes as in sewage.

In the treatment of sewage or milk wastes one of the primary functions of treatment is to oxidize and stabilize the organic constituents so as to convert such solids to unobjectionable materials and to yield an effluent that can be discharged without the creation of nuisance. In order to determine polluting power the most useful and practical yardstick today is the biochemical oxygen demand (B.O.D.) test which determines in general the amount of oxygen necessary to oxidize and stabilize the organic constituents of the waste.

Eldridge at the Michigan Experiment Station has determined that the 5-day B.O.D. of various forms of milk and milk wastes is approximately as follows:

Whole milk	102,500 p.p.m.
Skim milk	73,000 p.p.m.
Buttermilk	64,000 p.p.m.
Whey	32,000 p.p.m.

Ordinary domestic sewage seldom has a B.O.D. value over 250 p.p.m., so that the above wastes are from over 100 to 400 times as strong as sewage. Even wash water from a plant usually has a B.O.D. value of from 800 to 1,500 p.p.m., thus being several times as strong as sewage. Is it any wonder then that milk wastes are capable of creating serious nuisance conditions in a stream and operating problems in a municipal sewage plant?

As is true in a study of many industrial waste problems, one must not only deal with the wastes produced but also go within the plant itself to determine possible means of curtailing and reducing the volume and concentration of the wastes. In many industries it has been found possible to effect separation of various wastes, install equipment for recovery of valuable by-products and in some cases utilize recovered wastes. This frequently brings about material savings and economics in manufacture which have more than paid for the cost of the changes necessary in the plant.

In discussing the practical methods of preventing dairy waste nuisances, I have chosen to subdivide the methods into the following four subdivisions; namely, (1) Conservation, (2) Separation, (3) Recovery and (4) Treatment.

Conservation

Under "Conservation" I would include the prevention of all possible fluid milk losses entailed in the receiving and processing operations. There are few milk plants where it is not possible to effect a material reduction in milk losses by more careful operation or by installation of modern equipment. The superintendents of milk plants are usually allowed a certain maximum percentage loss of milk solids received in their plant and they take great pride in keeping this loss as low as possible. They do keep such losses low but these losses are based only upon the milk that reaches the weigh pan and does not take account of the milk which is not weighed. What of the milk that is lost through spills or left in the can after dumping?

When milk is being received and dumped at the rate of 10 to 12 cans a minute, as is frequently the case in large plants today, it is inevitable that some spills and loss of milk will occur. Here more careful dumping is indicated and automatic dumping appears to hold greatest promise of preventing accidental losses.

When milk is being received at a high rate it is also obvious that rapid dumping without provision for draining must result in considerable loss of milk, which at the present time is usually discharged with the can washings. The personal element enters into the efficiency of dumping milk and the actual amount of milk left in a can may vary from one quarter to as much as one pint at times when the milk is frozen. This loss in terms of milk handled amounts to from 0.3 to 1.0 per cent of the milk received.

These are, of course, losses to the farmer because such milk does not reach the weigh pan. However, such losses, from the waste treatment point of view, are costly to the milk plant where it is necessary

to treat the wastes and represent one of the greatest single sources of milk solids waste. They, therefore, warrant conservation measures.

In order to conserve the milk left in cans after the dumping operation, it is possible to install so-called drip savers ahead of the can-washer so that a large part of this milk may be collected and prevented from admixture with the wash water. This equipment is relatively inexpensive and can be used effectively to separate the greater part of the ¼ pint to 1 pint of milk left in the cans after dumping.

Another major loss in the milk plant frequently occurs in draining and washing of equipment. The installation of air compressors and the use of air for blowing out the lines of coolers and piping can do much to limit this loss. There is, however, still a considerable amount of milk left in the lines and the coolers which can not be blown out by the air. The use of a small amount of water for initial rinsing of this equipment and separate collection of the waste therefrom would undoubtedly still further reduce the quantity of milk solids which find their way into the waste or sewer line.

What actually can be accomplished in reducing milk losses? The extent of savings to be effected are indicated by the results at a recent installation in a plant of the Sheffield Farms Company at New Milford, Pennsylvania. The particular problem at the plant concerned the disposal of wastes. The plant is a bottling works in which the milk is received, pasteurized and bottled. It was handling at the time approximately 450 cans of milk a day and the total waste was 38,000 gallons. It had been determined by the State Department of Health that if the milk solids lost could be reduced by 50 per cent, treatment of the wastes would not be necessary. Accordingly, provision was made to collect separately the rinsings of the equipment and install a drip saver ahead of the can washer.

Before the changes in the plant were made, a catch sample of the wastes had shown a B.O.D. value of approximately 1,000 p.p.m. This was not, however, a representative sample as it was taken at a time when the greatest amount of milk waste was being discharged. However, after these changes were made, analysis of a composite sample showed that the wastes had a B.O.D. value of 150 p.p.m. which was far less than normally found in wastes from a plant of this type. Tests of milk solids indicated that of a total normal loss of 50 pounds per day, 24 pounds were actually removed from the wastes going to the sewer.

The results of tests of the wastes made with and without the equipment rinsings separated were as follows:

	Rinsings Left in	Rinsings Out	Per Cent Reduction
Total Solids	869 p.p.m.	585 p.p.m.	33
Volatile Solids	291 p.p.m.	90 p.p.m.	69
Suspended Solids	372 p.p.m.	188 p.p.m.	49.5
Protein	78 p.p.m.	33.5 p.p.m.	57
Fat	144 p.p.m.	34 p.p.m.	76

These results indicate that a remarkable reduction in the organic constituents of milk wastes can be effected within the milk plant itself. In some cases further treatment of the wastes would not be necessary and an investment in waste treatment facilities could be saved.

After having effected various savings of milk solids, as outlined above, the question logically arises as to their disposition. Should they be permitted to be disposed of in products for human consumption? Health authorities are not in entire agreement as to the proper disposal of milk solids saved at a plant by conservation measures. For example, referring to the use of drip savers, New York City policy requires that, where so-called "slop" milk is to be salvaged such saving will be permitted provided activated carbon or charcoal or other substance is placed in the container intended to be used for such slop milk, to give it a distinct color and to render it unfit for human consumption. This procedure has been adopted to prevent the possible use of unwholesome milk in the manufacture of milk products. It is thus seen that it is intended that such salvaged milk shall not be used for edible products.

It is recognized that it is impractical for the man dumping the can to hold it for fifteen or twenty seconds over the receiving vat. However, the suggestion has been made that instead of placing the can in a vertical position after dumping, it be placed at an angle of about 45° in a conveyor with the neck of the can extending over the dump tank. This position would permit drainage of the can without contamination of the milk from the conveyor mechanism or water on the outside walls of the tank. It is possible that this modified procedure would safely enable such drip milk to be saved and utilized and incidentally bring a greater return to the farmer.

Separation

Under "Separation" of wastes I would mention a few typical examples of what can be accomplished in the milk industry. As noted before, the polluting power of whey wastes is many times that of ordinary wash water from a milk receiving station. In fact, treatment of milk wastes is usually based upon the separate disposal of all milk wastes containing a high percentage of milk solids. Therefore, one effective means of reducing the problem of waste treatment at a cheese factory would be the separation of whey and the initial wash water from the other liquid wastes in the plant. In most plants this would not be a difficult procedure by providing a separate holding tank into which all whey and initial wash water could be stored. Daily removal of such wastes from the plant would be necessary.

The ultimate disposal of these wastes is, however, a problem. If farmers are to remove it for feeding purposes, separate cans and equipment must be provided for handling. A more satisfactory method, where possible, is the recovery of the milk solids remaining in the whey wastes. Separators have been installed in most plants so that the

whey can be separated and the butter fat removed for manufacture into whey butter.

Further work is being carried out by the milk industry to recover further solids from cheese whey, as it is recognized that such solids can have a marketable value. Experiments are being made to recover solids by the use of heat, together with lime treatment. A special hot roll drier may also prove successful in producing a whey powder. These recovery methods are, however, applicable only to the larger plants and it has been found that where the solids in the waste can not be recovered or used, a tank wagon or truck into which the wastes can be pumped and disposed of on isolated farm or wood land is a practical and satisfactory means of preventing the wastes from reaching watercourses.

The same general procedure for separation of other wastes at milk plants, such as buttermilk, skim-milk, etc., which are high in milk solids, is necessary if the liquid wastes are to be kept to a minimum concentration of milk solids. In all such cases the disposal of the milk wastes separated is a problem which must be handled by each plant according to the local facilities and conditions.

All unpolluted or only slightly polluted cooling or condenser water should be separated from the milk wastes, in order to reduce the volume of wastes, where subsequent treatment is necessary. At condensories, it has been found that the milk solids content in the vacuum pan condensate is so low that such wastes can usually be separated and discharged into the stream without the necessity of treatment. Such waste is usually relatively great in volume, amounting to from 1,000 to 1,500 gallons per 1,000 pounds of milk received. The B.O.D. value of such wastes is usually less than 50 p.p.m. and unless the dilution of the receiving stream is extremely limited such wastes will not create a nuisance.

Recovery

Separation of wastes is also a prerequisite for "Recovery" of by-products and here seems to be a great possibility of increasing milk plant profits and at the same time reducing the pollution entering streams. Preparation of skim-milk powder, either by the hot roll process or by spray driers, has been a profitable recovery process for many years. The manufacture and recovery of the casein from milk has also been practised for some time.

Recital of some of the experiences at a milk receiving station, creamery, butter plant and by-products plant in New York State may illustrate the practicability of further steps for recovering milk solids from wastes. The village where this plant was located was relatively small and had a sewage treatment plant consisting of a septic tank and sand filters. This treatment plant normally would provide adequate facilities for treatment of the domestic sewage but with a continuing increase in quantities of milk wastes, the plant became inoperative, the

tank filled with foul smelling solids and the sand beds clogged in a short time.

Briefly, the normal operation of the by-products plant consists of treating the skim-milk from the creamery with dilute acid to precipitate the casein. The casein is then separated, washed and dried. Wash water from the casein contains considerable protein and is further treated to save protein residues. The waste from the casein operation is then run into tanks where the albumin is precipitated and separated. The residual whey then goes to evaporating pans where the milk sugar is crystallized. The crude sugar is then washed, the wash water recirculated and the sugar again crystallized. The final residue is then made into poultry feed.

The outlet for most of the products is satisfactory but in the case of milk sugar is limited. Development of calcium and sodium lactate products, however, has given encouragement to further efforts along this line. The development of markets which will bring a profitable return on an investment holds promise of providing a satisfactory outlet for the by-products which can be produced.

The buttermilk from the butter operation has been dried on a hot roll and converted to a poultry feed. The butter wash, however, was discharged into the sewer system; the solids remaining in the waste were largely responsible for the conditions developing at the treatment plant. This wash water was subsequently removed and pumped into tanks with the casein wash water, treated with hydrochloric acid and the curd combined with the albumin to produce a satisfactory chicken feed. This change in process enabled the sewage treatment plant to recover and operate fairly satisfactorily.

In order to indicate the extent of savings in milk solids which can be effected, the following figures are significant. During the year 1933 this plant recovered 220,000 lb. of milk solids for use as poultry feed whereas during 1934, with approximately the same volume of milk received, the recovery amounted to 638,000 lb. In other words, 418,000 lb. of solids formerly discharged to the sewer system were reclaimed by careful separation of wastes and recovery of a marketable product.

It is recognized that recovery methods are not so simple as the brief description above would indicate and such recovery methods are applicable only to large plants or plants located within reasonable distance of by-products plants. It has been shown, however, that fairly complete recovery of all organic milk solids is possible and profitable.

Treatment

Even after all practical conservation, separation and recovery of by-products has been carried out at the plant, there will be a quantity of wastes containing milk solids which must be disposed of. Just as there are no two municipal sewages which are exactly alike or all local conditions the same, there are no two milk plants where the plant methods employed or the local needs are the same. Each milk plant must be studied by itself and in the light of many local factors which govern type and degree of treatment required.

New York State Studies

Studies of the operation and efficiency of a few typical milk waste treatment plants were carried out by the New York State Department of Health in 1930 and 1931 (H. H. Wagenhals and M. H. Bidwell). These studies were limited to a few days at each of the plants for the purpose of obtaining detailed engineering data and to collect composite samples for analysis to determine plant efficiencies.

Although a formal and complete report upon these investigations was not prepared, many of the findings and conclusions have since been confirmed by other investigations. Five milk receiving stations and one milk powder plant were studied and in all cases the wastes consisted exclusively of wash waters from cans, equipment and floors and did not include any wastage of surplus milk or discarded by-products of the plant operation. Normal plant operations were carried on each day during the tests. With the exception of the milk powder plant, the wastes produced were for relatively short periods, ranging from 4 to 8 hours each day.

It was found that the volume of waste and its concentration were not in direct proportion to the amount of milk received, thus emphasizing the necessity of studying any milk plant thoroughly before attempting to design a treatment works. The rate of flow and concentration were further subject to sudden changes and wide variations. One of the most significant of the conclusions from this work was that no generally applicable method of milk waste treatment had been developed which would satisfy all conditions of dilution, topography, isolation, etc., which are encountered.

In regard to septic tank treatment, there was found to be an appreciable reduction of the total organic matter and of the ultimate oxygen demand. However, the immediate and one-day oxygen demands were increased, indicating that the dilution necessary for the effluent in a receiving stream should be at least as great as would be required for the untreated wastes.

The following table gives average results of analysis of composite samples collected for two days, October 23–24, 1931, from milk waste treatment plant of Sheffield Farms, Inc., at Moravia, N. Y.

Septic Tank, Moravia, N. Y., 1930

	Raw Waste	Septic Tank Effluent	Per Cent Reduction
1 Day B.O.D.	48.3	114	136 (Increase)
5 Day B.O.D.	509	395	22
Chlorine Demand	14.4	24.9	73 (Increase)
Oxygen Consumed	312	65.9	78
Total Organic N	27.18	4.68	83
Total Solids	1,141	727	36
Volatile Solids	844	337	60
Free NH_3	1.5	20.0	1,200 (Increase)

The chlorination of milk wastes was studied at two plants. Here the purpose of chlorination was to delay decomposition until adequate dilution was available. Samples of wastes with a residual of over 0.5 p.p.m. maintained a residual chlorine content for 10–12 hours and even after 30 hours some residual was present. It was concluded that this type of treatment might be satisfactory where initial discharge of wastes was into a small stream which entered within a short distance a stream having adequate dilution.

The trickling filter was found to be effective in reducing the biochemical oxygen demand of the wastes. The reduction in organic content and clarification of the wastes was not so great in all cases as would be expected from this type of treatment but this may be explained to some extent by the relatively short periods of operation and long intervals of idleness during each 24-hour period.

The variable relation between the milk received and the volume of waste produced is indicated by the following table:

	Moravia	Interlaken	Peruton	Elba (Powder Plant)	
	Receiving Stations Only			Receiving	All Operations
Milk, Gal.—1930	2,490	656	1,509		
1931		1,253	1,312	8,150	8,150
Waste, Gal.—1930	6,000	1,310	6,660		
1931		3,000	6,270	33,200	58,500
Gal. Waste per Gal. Milk—1930	2.4	2.0	4.4		
1931		2.4	4.8	4.1	7.2

Studies of the trickling filter installations were made at the Sheffield Farms Milk Receiving Station at Interlaken and Peruton, N. Y., and the Dairymen's League Co-operative Association receiving station and milk powder plant in Elba. The Sheffield plants were studied both in 1930 and 1931 but the Elba plant only in 1931.

Following is a summary of engineering data regarding the three trickling filter plants and their operation.

	Interlaken		Peruton		Elba
	1930	1931	1930	1931	1931
Milk Rec'd, Gal. Daily	660	1,250	1,510	1,310	8,150
Vol. Wastes, Gal. Daily	1,310	3,000	6,660	6,270	58,500
Depth Trickling Filter	6		6		8
Operation, Hr. Daily	3.0	7.4	5	5	18
Rate of Dosage (m.g.a.d.) (during operation)	1.2	1.1	2.0	2.0	2.8
Cu. Ft. Filter/Lb. Milk Solids	141	84	137	av. 137	140

It will be noted that these filters are liberally designed, based on a modern standard of at least 80 cu. ft. of filter material per pound of milk solids. The short period of operation, however, with resulting long period of idleness each day gives a somewhat higher rate of application of wastes during operation than generally considered satisfactory.

Summarized results follow of the operation of these plants for the two-day test each year (1930–1931) based on composite samples of raw and filtered wastes:

	Interlaken ‡			Peruton			Elba		
	Raw	Filter	Per Cent Red.	Raw	Filter	Per Cent Red.	Raw	Filter	Per Cent Red.
1 Day B.O.D.—1930	23.3	23.5	1.1 (inc.)	18.9	13.4	29.0			
1931*	382.0	135.2	67.4	206	78.3	62.0	67.5	23.6	65.0
5 Day B.O.D.—1930	358.3	128.0	64.2	97.0	48.5	50.0			
1931	638.3	210.4	67.1	453	140	67.0	485.0	56.3	88.5
Chlorine Demand—1930	15.4	8.1	39.5	3.9	1.5	61.5			inc. †
1931	16.1	4.7	70.8	6.5	2.1	67.7	4.8	25.8	538.0
Oxygen Consumed—1930	169	109	35.5	70.0	40.4	42.3			
1931	310	200	35.5	62.0	47.0	23.0	283	103	63.6
Total N—1930	17.75	11.98	32.5	6.84	2.84	58.5			
1931	24.5	20.1	18.0	4.4	3.3	25.0	22.4	8.0	64.3
Total Solids—1930	1,540	1,378	10.5	1,460	976	33.8			
1931	4,570	4,208	7.9	659	666	−1.0	2,407	2,094	13.0
Volatile Solids—1930	659	567	14.0	559	256	54.2			
1931	1,262	1,353	7.2 (inc.)	217	118	45.5	540	299	45.2

* Raw wastes septic in pump sump in 1931.
† Accounted for probably by breakdown of sulfates.
‡ Plant in operation only 3 months before 1930 studies made.
Note—Results Interlaken and Peruton for B.O.D. and chlorine demand obtained from 2 to 4 catch samples in 1930 and 6 to 8 composite siphon-discharge samples in 1931 during entire operating period.
Results Elba plant obtained from average of series of catch and composite samples for two-day period—plant in operation for two months prior to investigation.

Analysis of the foregoing results indicates that a trickling filter, operated for a relatively long period (18 hr.) each day, was able to effect a greater reduction in the 5-day B.O.D. of the applied wastes than a filter operated for short periods each day. There is, however, no noticeable advantage as regards the one-day B.O.D. reduction. The amount of oxygen consumed and total nitrogen removed was also markedly better in the Elba plant, while the removal of volatile solids is approximately as effective as at the Peruton filter and far better than at Interlaken.

It is recognized that a few of the foregoing results of the New York studies are somewhat conflicting, but they indicate actual operating results and for the most part show that the trickling filter is a satisfactory device for treating milk wastes. Distribution of the flow to the filter over a longer period of the day should reasonably yield an improved effluent and also distribute the load on the receiving stream. This could be accomplished by providing a holding tank in which the

wastes, chlorinated sufficiently to prevent bacterial action and resulting acidity, could be stored and pumped at a reduced rate of dosage to the filter.

There are a large number of treatment methods which have been employed for milk wastes, but many have proven unsatisfactory because of inefficiency, high cost of operation, odor nuisances, etc. Septic tanks are not adaptable to satisfactory treatment of milk wastes because of the high acidity developed and the resulting inhibited activity of the desirable bacteria and other micro-organisms. A normal sewage sludge is not produced, but instead a heavy, offensive, solid scum layer is formed at the top of the tank. The effluent is not only offensive but contains large amounts of organic matter in soluble and colloidal form as well as considerable suspended solids.

A large number of septic tanks for milk waste treatment are, however, in use, but their only justification is the removal of gross solids such as curd and butter, which are found in wastes from certain milk processes. They have been occasionally used in conjunction with sand filters and in this way operate fairly well as pre-treatment devices, serving to remove the milk constituents which would clog the filter. A few sand filters are also in use but the relatively large area required, high cost, and the care and expense necessary for their proper maintenance have operated against their general adoption.

Cesspools and subsurface systems have proven impractical for all except very small installations where soil conditions are especially favorable. They usually clog quickly and require frequent cleaning or construction of new units.

The activated sludge process has in most cases also been found to be impractical requiring very careful operation, yielding only a limited degree of treatment and producing an odorous sludge which is difficult to handle.

The most common satisfactory methods of disposal of milk wastes in use today are, in general, four in number, namely: (1) Dilution, (2) Broad Irrigation, (3) Chemical Precipitation, (4) Biological Filtration.

Dilution is recognized as a satisfactory means of disposing of milk wastes and in fact there are many cases where more satisfactory stream conditions would be obtained by direct discharge of wastes into the stream, rather than by attempting to treat them in septic tanks. Experience has indicated that a flowing stream is better able to handle a fresh waste and maintain aerobic conditions than to dispose of a highly acid septic tank effluent possessing a much higher immediate oxygen demand. Therefore, where adequate dilution is available, corresponding to a ratio of about 50 to 1 for normal milk wastes, direct discharge is usually preferable to septic tank treatment.

In any consideration of dilution, however, it must be borne in mind that the primary governing factor upon which dilution requirements must be based is the actual milk solids loss from the plant and not the volume of milk wastes. It is obvious that wastes having a higher solids

content than represented by the 1 to 2 per cent milk solution, usually found in wash water, would require greater dilution.

In connection with dilution as a means of disposal it is found that most wastes are discharged from a milk plant during a relatively short period each day, thus imposing on the stream a high maximum load. There are some cases where a small stream could adequately handle such wastes if the flow from the plant were distributed over a longer period each day. For this purpose it is possible that a holding tank provided with a regulated discharge outlet would serve to "iron out" the peak periods of waste discharge. In such case, the practicability of chlorination of the raw wastes to delay decomposition and maintain the wastes fresh during the holding period is worthy of consideration.

Broad irrigation is satisfactory where adequate isolated land is available and proper maintenance of the irrigation field is provided. Such treatment has been used satisfactorily in California and in conjunction with chlorination for odor control. Here it was possible to utilize the wastes for irrigation of crops with satisfactory results. Experience in the East has been limited to a few installations and those have in general been satisfactory when properly maintained, except during the winter season when freezing has prevented their operation.

Chemical precipitation has been studied by many investigators. A summary of their work shows that clarification of milk wastes can be affected by the addition of copperas and lime and also by a few other chemicals. Acid will also effect a separation of casein to yield a relatively clear effluent. Careful operation is necessary and even under the best regulated conditions there is seldom a reduction of over 50 per cent of the organic constituents. Subsequent treatment by sand or trickling filters or in the municipal sewage treatment plant is usually required. It is generally concluded that the method is impractical for ordinary milk wastes but may be applicable to the more concentrated wastes as a pretreatment process.

One of the recent developments in the chemical treatment of milk wastes consists of an adaptation of the so-called Guggenheim process of sewage treatment. This process is essentially a chemical treatment plant in which the sludge produced is returned to the wastes entering aeration tanks as in the activated sludge process. Two such plants are now in operation, one at Glen Karn, Ohio, started September, 1936, and the other recently at Marshall, Indiana.

The treatment process involves the addition of coagulants, hydrated lime and ferric sulfate to the raw milk wastes and the aeration of the mixture for a period of about four hours. The wastes are then settled in a secondary settling tank and the effluent discharged to the stream. Sludge from the settling tank is continuously returned to the waste entering the aeration channels.

The Glen Karn plant is a cheese factory and the wastes consist of can, equipment and floor wash water, and a small amount of whey. The greater part of the whey is pumped to tank trucks and taken to a nearby plant for recovery of byproducts.

A summary of a few of the significant results obtained from analysis of composite samples follows:

GLEN KARN WASTE TREATMENT PLANT

	Raw Waste	Final Effluent	Per Cent Reduction
Total Solids	2,002	994	50
Vol. Solids	1,026	240	76.7
Susp. Solids	636	44	93
Total N	28.9	5.2	47.5
B.O.D.	1,095	83	92.3

These results indicate that this process is capable of producing a high degree of treatment and should adequately meet the needs of many situations. There is one prime requisite and that is that the plant must be carefully operated in order to function effectively. Chemical dosages must be regulated intelligently and the plant maintained in continuous operation.

Further work is now underway on a study by E. F. Eldridge, of the Michigan Engineering Experiment Station, of an experimental unit using this process for milk waste treatment in comparison with other processes.

Biological filtration has been found to provide the most generally applicable treatment process in use today, and most of the reports upon studies of milk waste deal with this treatment. Application of fresh milk wastes, with gross suspended solids removed, directly to trickling filters will effect a marked reduction in the B.O.D. and organic constituents of the wastes. The wastes, however, must be fresh and not permitted to become acid from lactose fermentation, for such acidity greatly inhibits biological action. Allowable rates of application will vary, depending on many factors such as strength of wastes, hours of operation, depth of filter, subsequent disposal of effluent, etc. A reduction of 80 to 90 per cent of the B.O.D. value of normal milk wastes can be expected when such wastes are applied at a rate of not over 1 m.g. per acre per day to a filter 6 feet deep. Greater depths of filter yield higher percentage reductions of organic constituents.

In general, it has been found that the trickling filters produce a satisfactory effluent when the rate of application is such that not over one pound of milk solids are applied per 80 cu. ft. of filter volume per day when filters 6 to 10 feet in depth are utilized. In other words, concentrated wastes must be applied at correspondingly lower rates so that the actual weight of milk solids applied to the filters is less than this figure. However, very strong wastes can not be applied to trickling filters with success.

For small plants a trickling filter constructed of lath and equipped with a tipping trough for dosing, as described by L. C. Frank and C. P. Rhynus in *Public Health Bulletin No.* **101**, December, 1919, can readily

be adapted to treatment of milk wastes. Such units can be constructed with materials which are relatively inexpensive and easily replaced. Housing of such units is necessary to prevent freezing in northern climates and also aids in controlling possible odor nuisance. Such units should be preceded by a holding tank which will provide distribution of flow over several hours each day. Such a tank should be drained daily so that septic conditions do not develop.

For the larger installations trap rock, gravel or even slag are satisfactory filter media. At an experimental plant in Wallington, Ohio, perforated condensed milk cans were used satisfactorily and at minimum expense as filter media. The danger of clogging trickling filters is largely eliminated if the grosser suspended solids are first removed and the B.O.D. of the wastes is not greater than about 1,200 to 1,600 p.p.m. Adequate ventilation is considered essential for maintained aerobic activity and the beds are frequently placed above ground elevation, thereby permitting sufficient circulation of air.

In a consideration of the trickling filter for treating milk wastes or sewage, it has been shown that it performs more effectively when dosed in small amounts at frequent intervals than with large amount at longer intervals. More continuous dosing, such as that provided by a revolving distributor, therefore, in this respect possesses advantages over the fixed-nozzle type of distribution. It has also been suggested that continuous dosing of a trickling filter and return of a portion of the effluent for re-passage through the filter would enable the greatest use to be made of the filter media and very probably result in a reduction of the required cubical capacity of the filter. This proposal corresponds in some respects to the return of sludge to the aeration tanks in the activated sludge process.

Recently considerable work has been carried out with trickling filters operating at high rates. H. O. Halvorson of Minnesota has investigated a process which consists in general of continuous dosing of a trickling filter made of special vertical tile through which air is drawn by means of a suction fan. Distribution is effected, using the head from a small dosing box above the filter, by applying the waste to a special revolving inverted cone distributor above the center of a circular bed. A surge tank is provided to store waste flows in excess of the capacity of the filter. From the resettling tank which receives the filter effluent, a portion of the effluent is returned to mix with the incoming wastes and the remainder discharged to the stream. Rates of application on the filter of from 20 to 25 m.g.a.d. appear to give an effective reduction in the B.O.D. of the incoming waste. Results at an experimental plant treating wastes having a B.O.D. of 2,500 to 3,500 p.p.m. have shown reductions of about 85 to 95 per cent, when operating at a 25 m.g.a.d. rate of application.

An installation of this process was made at Nunda, New York, in 1936 at a combined receiving station, creamery and milk powder plant. Most of the milk received was skim-milk, which was converted to milk powder by the roll process. Serious nuisance conditions had arisen

in the small stream passing through the village due to greatly expanded activities at the plant with resulting increase in volume of milk wastes. Investigations following this installation showed satisfactorily improved conditions in the stream, confirmed by the results of analysis of stream samples.

Preliminary 24-hour studies of the efficiency of this plant a short time after being placed in operation and before completely "broken in" are shown below. In order to remove grosser solids from the wastes, which were found to be clogging the filter unit when applied directly, a septic tank providing 6 to 10 hours detention had just been placed in use for pretreatment two days before the tests.

This resulted in a waste going to the treatment plant with a pH of from 4.4 to 6.3, indicating considerable acidity. Rate of application to the filter was unusually high, amounting to 37 m.g.a.d., including 63 per cent return of effluent to the filter influent. Based on the rate of waste flow, however, the rate was about 14 m.g.a.d.

	Raw Waste	Tank Effluent	Final Effluent	Overall Per Cent Reduction
Total Solids	1,421	946	827	41.8
Volatile Solids	1,147	661	549	52.2
Total Org. Nitrogen	32.4	21.6	10.7	67.1
Free Ammonia	1.2	3.6	10.3	−758
Oxygen Consumed	580	390	147	74.7
B.O.D.	706	535	435	38.4
pH		4.4–6.3	6.6–7.2	

These results show an overall reduction by the settling tank and filter of 74.7 per cent of the oxygen consumed, 67.1 per cent of the organic nitrogen, but only a 38.4 per cent reduction of the B.O.D. of the raw wastes. A further analysis of the work of the filter shows that it was accomplishing only a limited reduction of organic constituents, the major reductions being effected by the septic tank. The major changes effected by the filter were in the reduction of oxygen consumed by 63 per cent and organic nitrogen 50 per cent. About 31 per cent of the organic nitrogen was converted to free ammonia in the filter.

It was recognized that the plant was operating under adverse conditions after only a short period of prior operation. Plans were made to continue the studies later after lime feeding had been instituted to neutralize the acidity of the wastes. Unfortunately, however, the operations at the milk plant were transferred to another locality, making further studies impossible.

Where a municipal sewer system is available, this method of disposal is satisfactory, provided the sewage treatment works is not adversely affected thereby. Usually the discharge of wastes in a volume over 10 per cent of the sewage flow will produce unsatisfactory conditions in a settling tank and subsequent treatment units. In all

cases whey, skim-milk, etc., should be excluded. Even with a milk waste to sewage flow of less than 1 to 10 it is frequently necessary to take special precautions such as prechlorination of the sewage for odor control and also maintenance of the proper pH condition of the digesting sludge by the use of lime.

As storage of milk wastes soon develops acid conditions, with resulting odors and nuisance at the treatment works, and also makes the wastes more difficult to treat, it is sometimes desirable to construct a separate line to the municipal treatment plant so that the fresh wastes may be applied directly to a trickling filter in a fresh condition.

In closing, I would summarize with the following general conclusions:

1. Reduction in milk solids losses in the milk plant itself is practical and can result in greatly reducing the waste disposal problem.
2. Separation and direct discharge of unpolluted or only slightly polluted cooling and condenser waters is a satisfactory and effective means of reducing the required capacity of treatment works.
3. Separation and separate disposal of all milk wastes containing large amounts of solids such as skim-milk, buttermilk, whey, etc., is feasible and practically essential to assure satisfactory operation of waste treatment processes known today.
4. Recovery of by-products from milk wastes with consequent reduction in milk solids loss to the sewers is practical and economical at many plants.
5. Dilution and broad irrigation are recognized as satisfactory methods of milk wastes disposal under favorable circumstances.
6. Chemical precipitation is an effective means of securing clarification of milk wastes but without subsequent treatment seldom produces an effluent satisfactory to discharge into a small stream.
7. Pretreatment of milk wastes by chemical precipitation or trickling filters should be required where wastes representing over 10 per cent of the sewage flow are discharged to a municipal sewer system.
8. Chlorination is an effective means of preserving milk wastes and preventing the development of acid fermentation and odors where broad irrigation is employed or where the wastes soon reach a stream having adequate dilution.
9. Sand filters provide satisfactory secondary treatment but the cost of construction and operation precludes their general use.
10. Trickling filters provide the most effective unit in common use today for the treatment of milk wastes.
11. High-rate trickling filters, with return of effluent, produce results which are worthy of further consideration.

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Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Ill.

GADGET CONTEST

NEW YORK STATE SEWAGE WORKS ASSOCIATION, ELMIRA, N. Y., OCTOBER 15–16, 1937

First Award: Combined Sludge Grinder and Loader

By Wm. W. Watkins

Superintendent of Water and Sewage Treatment, Oneonta, N. Y.

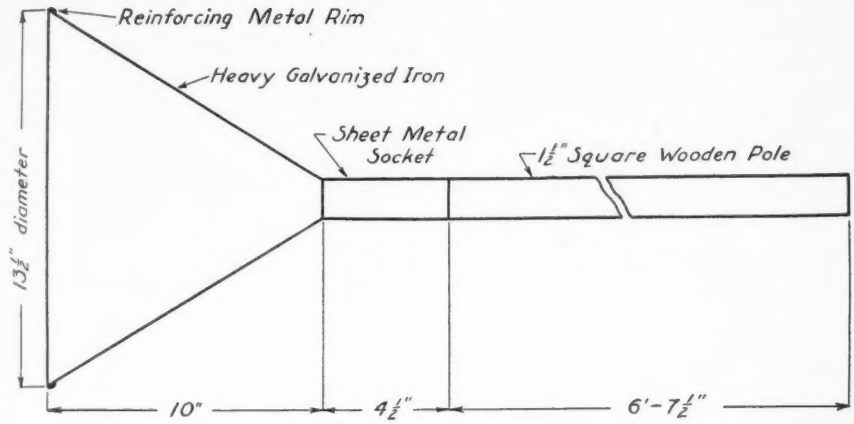
A grinder combined with an adjustable height loader to deliver the ground sludge either to bags or to a truck. Is used to process dried sewage sludge for use as a fertilizer and was constructed at a cost of $52 from old farm implements and an unused 3.5 H.P. electric motor (Fig. 1).

Second Award: Vacuum Scum Breaker for Imhoff Tank Gas Vents

By Wm. M. Foley

Chief Engineer, Schenectady County Home, Schenectady, N. Y.

A device to break up and moisten scum in the gas vents of a small Imhoff tank plant. The device has eliminated the hosing of the vents, resulting in considerable saving of water. Constructed of heavy galvanized sheet metal with a wooden pole handle as shown in Fig. 2.



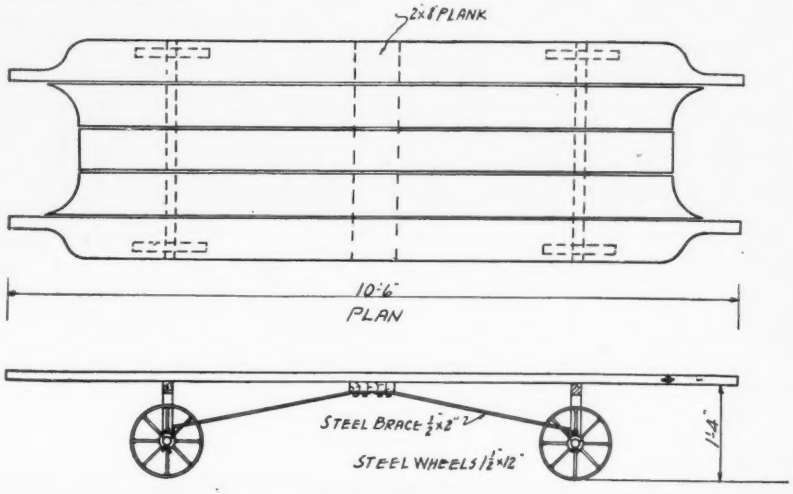
VACUUM SCUM BREAKER
FOR
IMHOFF TANK GAS VENTS
by
Wm. M. Foley, Chief Engineer
Schenectady County Home

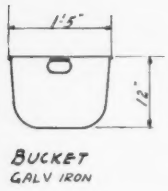
THIRD AWARD: DRY SLUDGE REMOVING EQUIPMENT

BY C. G. ANDERSON

Superintendent of Sewerage, Rockville Center N. Y.

Portable equipment to assist in removing dried sewage sludge from a drying bed (Fig. 3). The equipment can be easily handled by one or two men, with considerable saving of time. The track is made of 2-inch channels. The car will hold 12 galvanized iron buckets (Fig. 4).

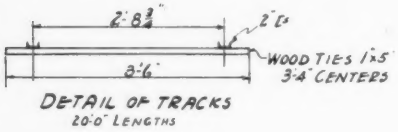


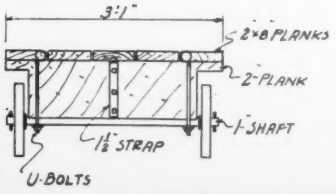


COST DATA

TRUCK

LUMBER	$ 2.50
4 WHEELS	10.80
MISS STEEL	2.00
TOTAL FOR TRUCK	$ 15.30
BUCKET	.60
S. TRACK PER FT	.15





DRY SLUDGE REMOVING EQUIPMENT

CENTRAL STATES SEWAGE WORKS ASSOCIATION, ST. PAUL, MINN., OCT. 21–22, 1937

FIRST PRIZE: SLUDGE SAMPLER OPERATING INSTRUCTIONS

BY GEORGE MARTIN

Superintendent of Sewage Treatment, Green Bay, Wis.

The sludge sampler (Fig. 1), is operated by lowering it to the desired depth with chain (*N*) attached to the valve stem (*A*), then holding it at that depth by chain (*N*) attached

to lifting bail (*G*) and replacing the chain attached to the valve stem (*A*). By so doing the valve drops away from its seat and sludge runs into the sampler. When the sample has been collected, the valve is closed and the unit raised by the chain attached to the valve stem (*A*).

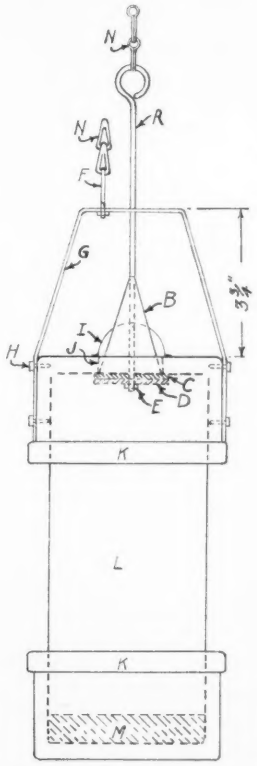


FIG. 1.—Sludge Sampler. List of Parts: *A*, 3/16" I bolt valve stem 7" long; *B*, Lead counterweight and valve guide, cone shaped 1½" at base, 2" high; *C*, Soft rubber gasket; *D*, Metal washer; *E*, Valve stem lock nut; *F*, 3/16" I bolt and nut; *G*, Lifting bail and valve stem guide, ⅛" × 1" strap; *H*, Cap screws; *I*, Metal spout soldered to cap; *J*, 1½" hole in cap at center; *K*, 3" screw caps; *L*, 3" nipple 6" long; *M*, Lead counterweight; *N*, Sash chain.

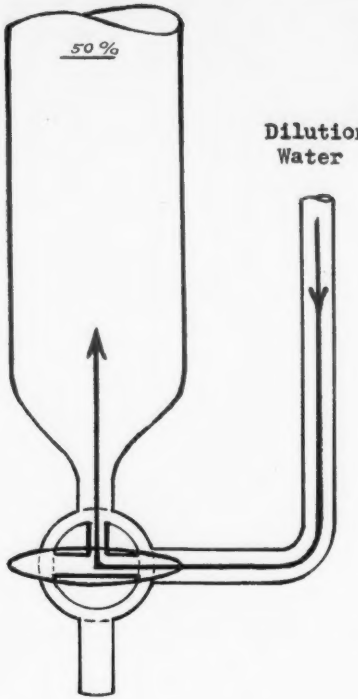
SECOND PRIZE: B. O. DETTE. AN APPARATUS FOR MAKING DILUTIONS FOR B.O.D. DETERMINATIONS

BY C. C. LARSON

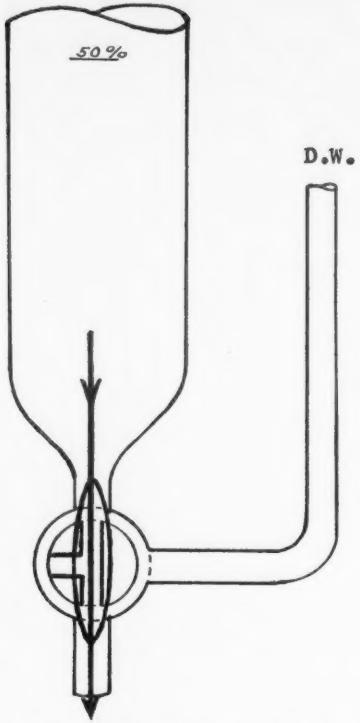
Chemist, Sewage Treatment Works, Springfield, Ill.

In making small dilutions the B. O. Dette is partially filled with dilution water, the sample of sewage is pipetted into the open top and the cylinder filled on up to the mark. In the case of 50 per cent or 25 per cent dilutions the cylinder is filled with dilution water to the half or three quarter mark, the bottle of sewage is placed on a nearby shelf and sewage is siphoned in until the cylinder is full.

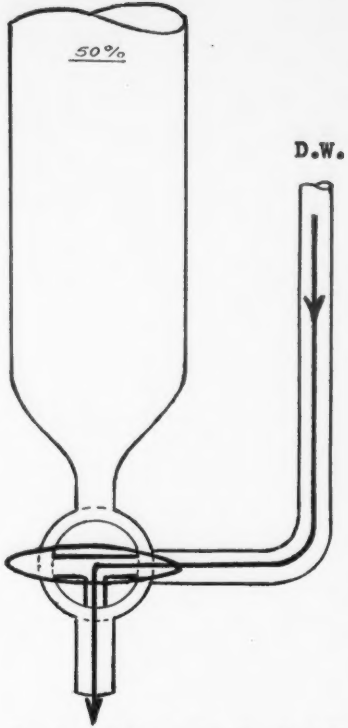
The capacity of th cylinder is 500 c.c.



Position of three way stopcock for filling cylinder with dilution water.



Transferring diluted sample into B.O.D. bottle.



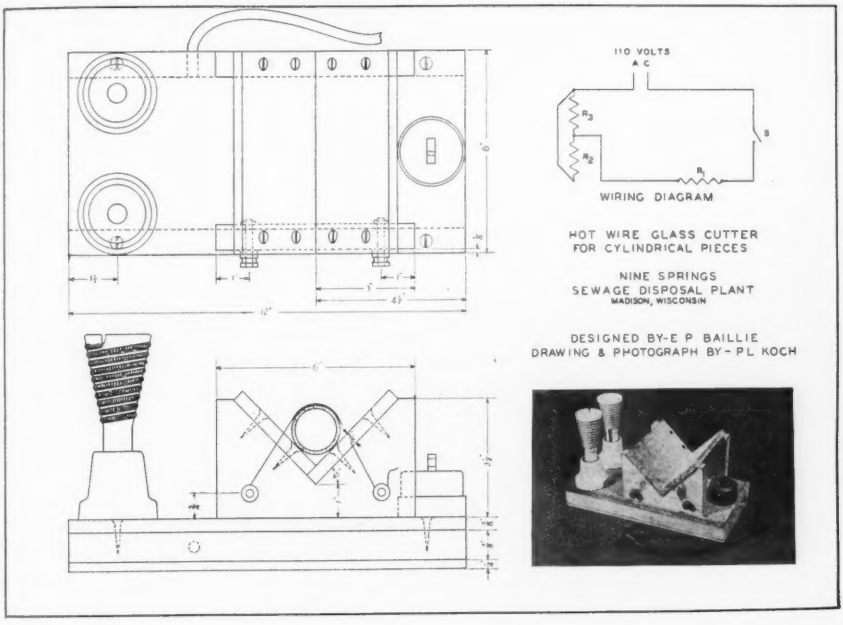
Drawing dilution water directly into bottle for blank determinations.

Third Prize: Electrical Glass Cutter

By Edward P. Baillie

Sewage Treatment Works, Madison, Wis.

The resistance labeled R1 is the wire which is heated to crack the glass. R2 and R3 are 500 watt resistances using the same kind of wire as R1. The sockets are porcelain heavy duty, the switch is an ordinary tumbler switch, the floor plate and the glass supporting trough are made of scrap transite and the framework of wood. The cutter is primarily adapted for use with cylindrical pieces (graduates, Imhoff cones, etc.) but may be used with a flat or irregular piece, provided the hot wire is brought in contact with it along the line to be cracked.



EXCERPTS FROM 1936 ANNUAL REPORT OF SEWAGE DISPOSAL, BOARD OF PUBLIC WORKS AND SANITATION, CITY OF INDIANAPOLIS, INDIANA

By C. K. Calvert, *Supt.*, Jan. 1 to Nov. 15, 1936, and
D. E. Bloodgood, *Supt.*, Nov. 16 to Jan. 31, 1936

Plant Operation Summary, 1936

The population of the city for 1936 is taken as 398,321. This figure indicates a more rapid increase than in the past few years.

Grit Chambers

The grit chambers were cleaned on an average of once a month. The material removed continues to be high in organic matter and seri-

ous objections were continually being made by employees of the Illinois Central Railroad who had to work in the vicinity of the grit dump. As a possible remedy to this situation, the Jeffrey Manufacturing Company was given an opportunity to do some experimental work on grit washing. It is gratifying to report that their work was successful and that the plans now made call for the modernization of the West Street Grit Chamber.

A proportional weir was designed for the north channel of the West Street Grit Chamber. After some modification it operated very well, giving a velocity of 1 foot per second. The quantity of screenings increased and skimmings decreased as compared with the past several years. The quantity of grit removed was the lowest since 1931.

Clarification

There were no days during this year when the clarification plant did not operate at least part of each day. Attention should be called to the solids in the raw sewage. They were not quite so high as in 1935 but were much higher than in any year since 1929. The extra solids in 1935 were thought to have been largely due to the ground garbage put into the sewage during the summer and fall of that year.

The per cent of sewage treated in the primary settling tanks was increased with the hope of increasing the overall removal by clarification. There was an improvement over the 1934 removal but a decrease below the 1935 results. Here again the addition of ground garbage may have had its effect.

The solids content of the primary sludge was lower than for the past years, except for 1935, when the solids were decreased to prevent sludge line stoppage. The habits then developed by the operators have lasted through the present year. This, of course, partially explains the increased volume of sludge, though it should be mentioned that the pounds of solids per million gallons was increased.

The clarified effluent delivered to the secondary treatment plant had less solids in it than it had had for the past two years.

Secondary Treatment Plant

The quantity of sewage given secondary treatment was the lowest since 1932. The explanation of this is that there were 26 days when the secondary treatment was shut down to make connections to the new additions.

The amount of solids removed by plain aeration was practically the same as for 1934. Attention should be called to the additional poundage removed, per million gallons, by plain aeration during the months of November and December, when the load on the old plant was reduced by the amount treated in the new units.

During the year No. 1 Plant was used as a control unit, except in the last two months in the year, when new sections of the plant were used for this purpose. The quantities treated by activated sludge, on

a unit basis, may not have been quite as high as for previous years, yet it should be said that the plant was operated in such a manner as to give the best of operating conditions. The loadings on the plant were largely controlled by the use of the aeration machine (see page 27) which has been in the process of development in the laboratory since December, 1932. With this machine it is possible to determine the oxygen demand of the activated sludge each day. Fluctuations from the normal indicated excessive or decreased loadings on the plant. By proper interpretation of results, it was possible to make changes in aeration period, air quantity, and sewage load, etc., that brought about operation results not heretofore experienced at Indianapolis. The problem of bulking was met and it was found that it could be controlled by proper loadings of the sludge with sewage. The improved removal in total organic nitrogen by activated sludge is of particular interest as this has never been experienced before. It has been found that the activated sludge plant seems to perform more satisfactoy when the nitrates are between 6 and 8 p.p.m., than when they are either above or below these figures.

Further experiments were made using chlorine in activated sludge. Addition of chlorine, together with the air, was tried but no results of importance were obtained. The samples of steel and iron suspended in the air lines carrying air and chlorine, were not affected by the chlorine.

Sludge Disposal

Digestion lagoons No. 1, 2, 3, and 4 were being cleaned. Much of the material was hauled away by W. P. A. trucks and used as fertilizer at the city parks, nurseries and golf courses. The weather was not the best for a good year of hauling by the market gardners. For them the ground must be either dry or frozen at the proper season or they can not spread the sludge. The new pit No. 12 was put in service during the year. Work was started on building pit No. 13. A new ten-inch sludge line to the pits from the activated sludge plant was laid so as to give more capacity and because of failure of the old line.

River Condition

The months of June, July, August and September were very dry, with but little water in the river. There was one new minimum daily flow established on September 13, when the sewage flow and river flow amounted to only 109 cu. ft. per second, and of this the clarification sewage made up 56 c.f.s. There were many days when no oxygen could be found at Station 19, which is 10.75 miles below the plant. It is disappointing to observe that the dissolved oxygen in the river above the city was lower than we hoped to be able to maintain, when the entire plant is placed in service on the activated sludge process. The B.O.D. figures, however, do not indicate as much pollution as the low content of dissolved oxygen. It was possible to make only two boat trips to

Waverly during the year. There were no unusual changes in the stream, either as to change of course or condition of the water as compared with 1935.

Industrial Wastes and Interceptors

The work under these particular headings did not get started until rather late in the year. The efforts were largely concentrated upon the developing of a map which is usable for work of this kind. Needless to say, to work efficiently upon this endeavor, it is necessary to have clearly in mind the general lay-out of all interceptors and larger sewers and the location of the various industries in relation to them. Numerous inspections of garages and filling stations were made to see how efficiently their catch basins and grease traps were working and being maintained.

Summary, Operation and Laboratory Data

Per. Capita per Day Figures

Gallons of Sewage	118
Suspended Solids, grams	155
B.O.D. (5-day), lb.	0.26
Nitrogen, grams	12.6
Grease, grams	29.1

Clarification Plant, Summary of Operation

	Million Gallons per Day	Coarse Screenings, Cu. Ft. M.G.	Skimmings, Cu. Ft. M.G.	Grits, Cu. Ft. M.G.	Pri. Slg., Lb. Dry Sol. per M.G.	Per Cent Solids Removed in Clar.
Jan.	35.76	0.70	.40	2.25	1105	36
Feb.	38.88	1.05	.20	4.76	1149	37
Mar.	40.34	0.75	.57	4.14	1184	41
Apr.	41.17	0.58	.29	3.24	1060	39
May	40.91	0.51	.43	4.09	1103	40
June	43.99	0.41	.50	2.67	921	36
July	48.38	0.40	.52	2.45	706	29
Aug.	49.57	0.58	.34	2.69	982	35
Sept.	49.43	0.56	.44	0.21	1041	38
Oct.	46.00	0.88	.44	0.17	1303	43
Nov.	36.74	1.07	.37	4.50	1433	42
Dec.	36.34	1.21	.69	2.73	1403	37
Tot.	15,453.27					
Average	42.22	0.70	.43	2.72	1100	38

CHEMICAL DATA

Suspended Solids

	* Raw Sewage P.p.m.	Rapid Settler Eff. P.p.m.	Clarified Sewage P.p.m.	Plain Aeration Eff. P.p.m.	Activated Sludge Eff. P.p.m.	Pri. Sludge Per Cent	Plain Aeration Sludge Per Cent	Return Sludge Per Cent	Mixed Liquor Per Cent	Resettled Act. Slg. To Pits Per Cent
Jan.	372	186	239	60	13	4.39	4.52	0.29	0.16	4.51
Feb.	334	156	210	73	19	5.38	4.91	0.31	0.17	1.96
Mar.	344	156	203	62		5.40	5.06			
Apr.	325	130	184	57	12	5.17	5.29	0.24	0.12	
May	330	133	197	61	12	4.98	4.97	0.80	0.30	3.56
June	312	116	201	66	22	4.37	4.72	0.83	0.27	2.98
July	279	137	197	68	9	3.78	4.40	0.78	0.28	3.01
Aug.	333	144	215	71	10	4.68	4.25	0.75	0.28	2.61
Sept.	325	131	200	64	17	4.87	4.39	0.50	0.22	2.87
Oct.	366	134	209	70	12	5.10	4.59	0.58	0.24	3.23
Nov.	412	153	239	57	15	4.89	3.34	0.66	0.26	2.05
Dec.	456	176	287	54	11	5.12	4.43	0.70	0.26	2.05
Avg.	346	147	215	64	13	4.84	4.58	0.64	0.25	2.78

* Calculated.

CHEMICAL DATA

5 Day Bio-Chemical Oxygen Demand P.p.m.

	* Raw Sewage	Clarified Sewage	Plain Aeration Effluent	Activated Sludge Effluent	Effluent to River †
Jan.	302	267	121	23	124
Feb.	248	218	105	39	109
Mar.	263	203	99	—	107
Apr.	206	179	73	11	128
May	253	219	106	21	90
June	252	222	108	18	109
July	216	219	101	11	100
Aug.	134	224	113	18	116
Sept.	214	184	79	14	78
Oct.	223	187	79	11	80
Nov.	281	235	73	16	49
Dec.	278	260	94	16	93
Avg.	256	220	97	17	101

* Calculated by making the assumption that the same ratio in B.O.D. and nitrogen exists in primary sludge as it does in clarified sewage.

† Weighted according to flow.

SLUDGE ANALYSES DRY BASIS

	Chloroform Soluble			Nitrogen		
	Primary Sludge Per Cent	Plain Aeration Per Cent	Activated Sludge Per Cent	Primary Sludge Per Cent	Plain Aeration Per Cent	Activated Sludge Per Cent
Jan.	21.68	29.18	9.32	2.88	3.89	4.11
Feb.	19.41	27.03	8.68	2.48	3.27	4.32
Mar.	19.14	29.02	9.18	2.62	3.50	
Apr.	19.83	29.97	—	2.69	3.65	4.02
May	22.68	29.72	7.70	2.93	3.72	4.65
June	24.88	30.21	7.24	2.92	3.88	5.06
July	23.65	30.87	6.93	2.94	4.31	5.01
Aug.	19.24	28.38	8.46	2.97	4.13	5.25
Sept.	19.02	29.66	7.89	2.83	3.91	4.86
Oct.	20.94	28.79	8.57	2.83	3.70	4.66
Nov.	21.38	30.27	9.01	3.27	3.92	4.92
Dec.	21.48	29.93	8.36	3.18	3.53	5.34
Average	21.67	29.27	8.33	2.88	3.79	4.80

COST OF OPERATION PER M.G. OF SEWAGE TREATED

	Grit Chambers and Interceptors	Clar. and Pumping	Secondary Treatment Plant	Sludge Disposal	Railroads and Lands	Total
Jan.	$0.92	$4.04	$ 5.51	$1.47	$0.09	$12.03
Feb.	0.97	3.84	4.09	0.43	0.15	9.28
Mar.	0.73	3.99	5.61	0.48	0.23	11.04
Apr.	1.54	5.34	17.66	0.35	0.32	25.21
May	0.76	3.92	4.31	0.49	0.34	9.82
June	0.75	3.47	3.82	0.26	0.35	8.65
July	0.60	2.95	3.78	1.40	0.20	8.93
Aug.	0.70	2.81	3.20	4.37	0.20	11.28
Sept.	1.08	3.17	3.61	0.49	0.13	8.48
Oct.	0.91	3.33	3.88	0.67	0.26	9.05
Nov.	1.07	3.30	5.23	0.75	0.09	10.44
Dec.	1.00	3.29	5.72	0.87	0.12	11.00
Average	$0.89	$3.58	$ 4.59	$1.09	$0.21	$10.36

WHITE RIVER DATA

	Above Plant			6.25 Miles Below Plant	5 Day B.O.D. in Effluent Discharged to River
	C.f.s. Flow *	P.p.m. Oxygen	Thousand lbs. D.O. Available	P.p.m. Oxygen	Thousand Pounds Day
Jan.	457	11.0	27.2	8.5	37.43
Feb.	2382	—	—	—	36.75
Mar.	2063	10.6	118.0	10.0	40.57
Apr.	1392	10.4	75.0	8.6	48.40
May	1419	6.9	53.0	7.3	50.59
June	374	6.7	13.5	0.8	59.24
July	165	2.8	2.5	0.0	64.80
Aug.	159	2.8	2.4	0.0	67.58
Sept.	179	3.9	3.8	0.1	52.68
Oct.	311	6.4	10.8	0.8	48.40
Nov.	1363	11.1	82.0	6.8	28.20
Dec.	633	11.0	38.7	2.6	28.25
Average	906	6.7	38.8	3.4	46.88

* Includes sewage flow.

OPERATION OF IMHOFF TANKS *

BY CHANNEL SAMSON

Superintendent of Sewers, Town of Townawanda, Kenmore, N. Y.

The Town of Tonawanda commenced treating its sewage in 1924. Plans for the plant were started in 1922 and the treatment plant was completed and put into operation in 1924. The plant, as originally laid out and constructed, consisted of two cone-shaped Imhoff tanks, one open sludge drying bed, and a small plunger-type sludge pump for transferring sludge from the tanks to the drying beds. These tanks, unlike most of the circular tanks designed today, are not of the radial-flow type, but have an inlet at one side with an outlet diametrically opposite. The gas vent is a circular concrete well at the center of the tanks. In 1927 the sewage load had increased to the extent that it was necessary to add two more circular tanks, and additional glass-covered sludge drying beds. Since that time, no open drying beds have been operated. The continually increasing load on the plant made necessary the installation in 1931 of a by-pass through which storm flows greatly in excess of the plant capacity can be handled. This satisfactorily took care of the storm flows, but the normal dry weather flow continued sufficiently heavy so that it became necessary in 1933 to provide equipment for the chlorination of the plant effluent to pro-

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, N. Y., October 15–16, 1937.

tect the sanitary quality of the stream into which the effluent was discharged. This first unit consisted of a 320 pound capacity, manual control, solution feed, panel type Wallace and Tiernan chlorinator. Equipment was also provided at this time for making determinations of settleable solids, pH and residual chlorine.

Since the opening of the plant in 1922, only domestic sewage free from trade wastes has been handled. Several industrial plants have been under construction in the township during the past year and are about ready to go into operation. It is anticipated that these wastes will give us plenty of trouble at the plant unless suitable pretreatment and separation are provided by the industries, and a careful investigation of this matter is being undertaken.

The capacity of the treatment plant at this time is 2 m.g.d. for a population of about 20,000 persons. There are approximately 78 miles of sanitary sewers.

As previously stated, the plant originally contained two circular Imhoff tanks 50 ft. in diameter. These tanks were designed with the gas vents equivalent to 20 per cent of the surface area of the tanks. The two additional tanks, added in 1927, were designed with one-half as much area for gas vents, or 10 per cent of the gross surface area. We have found that much more difficulty has been experienced in the control of the tanks with the smaller gas vents. We believe that ample gas vents are essential for proper functioning of such tanks. The average scum depth on all four tanks during the past five years has been 18 in. during warm weather, which has increased to about 3½ ft. during cold weather. The material skimmed daily from the flowing-through section of the tank is added to the gas vents with the scum. This has proved to be a very satisfactory procedure for disposing of this material.

At one time, a great deal of trouble was experienced during the winter months in preventing the accumulation of gas under the frozen scum in the gas vents. It was found necessary to keep an operator busy with an iron bar opening holes in the frozen scum to provide avenues of escape for the gases. In 1935–36 wooden covers were built to cover the gas vents, with the idea of preventing the scum from freezing so solidly and perhaps making it possible for the gases to escape through the unfrozen scum. The use of the covered gas vents in winter prevented the freezing of the scum and allowed the gases to escape freely. During June, 1937, a bad flood floated the covers off the gas vents and they were found to be in such poor condition that it was decided not to replace them. Instead, iron gratings have been installed with 8 in. square openings, with arrangements for fastening heavy tarpulin covers over them in the winter, to prevent freezing of scum.

The Imhoff tanks are 32 ft. deep, with total sludge storage capacity in the four tanks of 40,244 cu. ft. With the sewage flows arriving at the plant prior to 1935, this was ample and normal operating conditions existed. Since that time, however, we have found this capacity to be

too small and trouble has been experienced in keeping the tanks in good condition. Instead of operating with a maximum sludge depth of 11 to 11½ ft. it has been necessary to allow sludge to accumulate to a depth of 13 ft., or 1 ft. above the slot, which is highly undesirable. It is expected that this condition will be corrected in 1938. The sewage flow through the tanks is equalized manually by the adjustment of the gate valves in a distribution chamber. Bi-monthly checks on the sludge depth in each of the tanks carried out during the past five years have shown variations of only 3 to 6 inches.

Foaming has been a great problem for the past six years. We always have had foaming during April, May, and June of each year. Because of the crowded condition of the plant, it has not been possible to control foaming by holding down the sludge levels. During 1936, prechlorination was provided for experimental purposes and excellent results were obtained, although a small amount of foaming did occur. However, in 1937 prechlorination was started on the first of March. At the same time, a schedule calling for the pumping of 2 ft. of sludge from each tank each month was started. Later, when the weather made it possible to dry sludge more rapidly, two pumpings each month were undertaken. With the addition of 12 p.p.m. of chlorine to the influent sewage and this schedule of sludge pumping, it has been possible to control foaming in our tanks. Because of an error in the operation of the control valves in the distribution chamber, one tank was found to be receiving twice its proportionate amount of solids. This tank showed signs of foaming, but by adding additional chlorine to the inlet chamber at the rate of 9 p.p.m for 24 hours and then letting the tank rest 24 hours, this condition was corrected and the tank was placed in operation with the others.

In order to have the advantage of prechlorination, we installed a 379 lb. Wallace and Tiernan automatic control chlorinator. Then the problem of scales arose so we eliminated the scale and set up a battery of four 1-ton chlorine containers, along with an electrically controlled valve, so there is always a flow of gas to each machine, for whatever purpose may be necessary. There is a total capacity of 680-lb. per day, which is enough for present needs.

In this plant, we have found that the sludge pumping schedule is very important. As long as we can pump sludge monthly in cold weather and twice a month in hot weather, the tanks are kept in satisfactory condition. It has also been found that if we pump too long at one time and do not retain a sufficient volume of digested sludge to react properly with the fresh solids, we get into trouble.

We had an interesting experience with one of our tanks during the flood of June, 1937. Following the flood, all of the sludge came to the surface and we had no solids in the bottom of the tank. It took four months of hard work, with regular hosing, the use of lime and also chlorine, to put this tank back into good operating condition. We added lime daily at the rate of 50-lb. per m.g., chlorine at the rate of 5 p.p.m. and plenty of labor and water pressure to break up and sink the solids.

It has been observed that the chlorine demand, referring now to our regular postchlorination and not to prechlorination which is used only to control foaming, is lowest immediately after sludge is withdrawn and that it steadily increases to a maximum when the tanks are again ready for pumping. Also, the efficiency of prechlorination is much improved if the sludge depth in the tanks is kept at a minimum. This does not refer to the ordinary change in operating condition usually observed in a tank with high sludge level and the same tank after it has been pumped. There seems to be a further improvement when using prechlorination if the sludge level is kept at a minimum. In recent years, the digested sludge drawn from these tanks has been unusually thick and heavy. No equipment has been available for running moisture content, but plans are being laid for a more complete laboratory in the near future.

Total sewage handled through the tanks in 1935 averaged 2.36 m.g.d. and in 1936 2.71 m.g.d. The recording of flow of sewage is by means of a Cochrane V-Notch Recorder which has been checked and always found to be in first class shape.

The total amount of sludge pumped in 1935 was 128,400 cu. ft., and in 1936, 141,000 cu. ft. It is estimated that the volume for the entire year 1937 will amount to 160,000 cu. ft. The amount of dried sludge removed from drying beds in 1935 was 40,200 cu. ft., in 1936, 51,000 cu. ft. and estimated for 1937, approximately 60,000 cu. ft.

Average pH range of sludge in 1935 was 6.8 and in 1936, 6.9.

SEPARATE SLUDGE DIGESTION WITHOUT HEAT*

By L. R. Smith, *Superintendent of Water and Sewers, Canton, N. Y.*

The Village of Canton, New York, is located in St. Lawrence County and is one of the most northerly municipalities in New York State having a sewage treatment plant. As would be expected, the winters here are generally long and cold. The U. S. Weather Bureau has described the climate at Canton as follows: "the most pronounced climatic factor of this region is the long rigorous winter. Five months of winter is the least one may expect here, and more often than otherwise conditions of winter will overlap the adjacent months." However, in common with many other areas, the winter of 1936–37 was unusually mild at Canton.

The permanent population is about 2800 and there is an additional population of 1200 at St. Lawrence University and the State School of Agriculture. This gives a population of 4000 during most of the year.

The sewage treatment plant at Canton was constructed in 1935 as a P.W.A. project, the plant itself costing $22,000 and the changes necessary to carry the sewage to the treatment works costing an additional $20,000, making a total of $42,000.

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, N. Y., October 15–16, 1937.

Description of Plant

The treatment plant is of the plain sedimentation, separate sludge-digestion type, with no secondary treatment provided. The plant was designed on a population basis of 5000 and the average flow of sewage has been about 600,000 gallons per day. The sewage entering the plant passes through bar screens having 1½ in. openings. The sewage is heavily chlorinated prior to sedimentation to give a residual in the effluent of at least 0.5 p.p.m. The sedimentation tanks have a detention capacity of about 3 hours. The effluent is discharged into the Grass River through an 18 in. outfall.

Fresh sludge from the settling tanks is pumped daily into either of two digestion tanks, each being 15 ft. by 22½ ft. in plan and 16 ft. deep. The sludge capacity of these tanks is approximately 2 cu. ft. per capita. The digestion tanks are surrounded by an earthen embankment which extends to the top of the outer walls, in order to provide insulation. No provision is made for recirculation or agitation of the sludge in the digestion tanks. The only mixing in the tanks is done by breaking up the scum with a hose. The digested sludge may be removed to the drying beds either by gravity or by pumping. The drying beds have a total of 2500 sq. ft. and are provided with glass covers.

Plant Operation

This plant was placed in operation on September 25, 1935. Table I gives a monthly record of temperature conditions.

Table I

Month	Air Temp. Deg. F.	Temp. of Sewage at Plant, Deg. F.	Digestion Tank Temperature, Deg. F.		pH of Sludge	
			No. 1	No. 2	No. 1	No. 2
Dec. 1935	15.0	43.4	No record		7.4	
Jan. 1936	14.2	41.7			7.5	
Feb.	12.1	40.3			7.6	
March	33.8	42.0	44	45	7.2	7.3
April	40.3	43.8	46	48	7.4	7.2
May	56.6	51.7	56	—	7.4	—
June	64.2	58.4	62	—	7.2	—
July	67.8	62.2	65	65	7.2	7.4
Aug.	65.0	64.0	67	66	7.8	7.3
Sept.	60.2	61.0	64	66	7.8	7.5
Oct.	47.7	56.0	57	57	7.6	7.4
Nov.	30.0	50.4	48	52	8.0	7.6
Dec.	25.0	47.0	44	42	7.7	7.4
Jan. 1937	27.3	43.6	44	45	7.5	7.8
Feb.	23.4	42.6	43	44	7.5	7.7
March	22.8	42.5	44	45	7.5	7.8
April	42.5	43.7	46	48	7.6	7.8
May	56.6	50.6	54	52	7.8	7.5
June	64.7	57.7	60	58	7.5	7.3
July	71.1	62.5	68	67	7.6	7.5
Aug.	71.9	65.0	69	69	7.5	7.6

Lime is added daily to the sludge before it is pumped to the digestion tanks. The pH of the sludge in the digestion tanks is given in Table I. The amount of lime added has averaged 45 lb. per day. The first sludge was removed from the digestion tanks on April 28, 1936 and nine additional batches of sludge were removed up to the end of January, 1937.

The average drying time of the sludge during this period was 30 days. Removal of digested sludge was again started on June 25, 1937 and six batches have been removed since that time. The average drying time during the past summer has been 10 days, indicating a marked improvement in the quality of the sludge. The maximum temperature which can be reached in the sludge in the digestion tanks without the addition of artificial heat appears to be about 70° F., this temperature being reached late in the summer.

Although the sludge which was removed to the drying beds during the first year of operation was not of very good quality and dried rather slowly, the results during the second year have been much more satisfactory. This has been due partly to better operation of the digestion tanks. Dried sludge has been disposed of to farmers without cost to the village.

TABLE II.—*Sludge Removed*

Date	Volume (cu. ft.)		Drying Time (days)
	Tank No. 1	Tank No. 2	
April, 1936		1850	30
May	1400		48
July		1320	38
Sept.	1980		33
Oct.		1800	21
Oct.	1900		40
Dec.		1800	28
Jan., 1937	2300		16
Jan.	800		17
Jan.	900	(Frozen—not removed until spring)	
			—
			Average 30 days.
June, 1937		2000	13
July		1500	9
July	1800		8
July		3000	15
Aug.		2000	6
			—
			Average 10 days.

Odor conditions around the plant have greatly improved since the first few months of operation, due to liberal chlorination of the sewage and to better digestion of the sludge.

Sludge drawn in September, 1937, was thin and drained rapidly,

and had very little odor. It dried and was removed in five days. This represents the best sludge to date and is a vast improvement over that removed in the spring of 1936.

Experience at this plant indicates that much better digestion of sludge is possible when the sludge enters the digestion tanks in as fresh condition as possible. The sewage reaching the plant is not septic and is chlorinated immediately after passing the bar screen. Sludge is removed from the settling tanks daily and is treated with lime before being pumped to the digestion tanks. It is believed that by this means, i.e., preventing septic action, the sludge is given a good start toward proper digestion. By keeping the bar screen, the influent channel and the sludge sump cleaned daily the maintenance of a fresh sludge is aided.

Operation costs, including labor, repairs and chemicals, averaged $17 per million gallons of sewage treated during the first year and $12 per million gallons treated during the second year of operation.

SEPARATE SLUDGE DIGESTION IN HEATED TANKS *

By Herbert O. Johnson, *Superintendent of Sewers, Belgrave Sewer District, Great Neck, N. Y.*

The digestion of sewage sludge in heated separate sludge digestion tanks is a comparatively recent innovation. As late as 1926 this process was still in its early stage of development. It was found, however, that under controlled conditions the rate of digestion could be greatly accelerated and a well digested sludge obtained. Optimum conditions required a pH of from 7.0 to 7.2, temperature from 80 to 95 degrees F., and an adequate amount of digested sludge in the tank to act as seed. The operator's duties are to obtain these conditions and to maintain them.

In simple language the operator's work, as far as sludge is concerned, is to take a highly putrescible, vile smelling liquid mass of solids removed from sewage, usually by sedimentation, and to convert them into a comparatively stable and inoffensive form that will dewater easily before final disposal. This conversion is a biological phenomenon accomplished by anaerobic and facultative anaerobic bacteria which are present in sewage sludge in large numbers. These bacteria effect digestion by attacking the unstable organic matter in the raw sludge and reducing it to a more stable form. The activity of the bacteria depends largely on the conditions under which digestion takes place. These bacteria are very sensitive, particularly as to the reaction or pH of the liquid mass and the temperature. An acid reaction inhibits bacterial action, with a consequent retardation of the rate of digestion, and will lead to foaming and other operating difficulties. The pH of the sludge may be maintained at or near the optimum point

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by additions of lime or other alkalis, but this is usually not necessary, as under balanced operation of a digester a proper pH is maintained. Two factors of operation enter into this problem:—the amount of raw sludge added daily to the tank and the amount of digested sludge removed. Proper operation, as dictated by theory and proven in practice, requires that the amount of dry solids added to the tank daily as raw sludge shall not exceed 3 per cent to 5 per cent of the amount of dry solids in the tank as digested sludge. An excess over ratio may overcome the buffering action of the digested sludge, lower the pH and permit acid digestion, which is often accompanied by foaming. In withdrawing digested sludge care must be taken not to reduce the amount in the tank below that required for seeding the fresh solids. At the Belgrave digester a minimum of 22 in. of dgested sludge is required. Actually about 3 ft. of sludge is kept in the tank. Since the lowest sampling pipe extends down to this level it is a simple matter to check and maintain the predetermined amount.

If the temperature of the sludge in the tank is kept between 80 and 95 degrees F. and the proper reaction is maintained, the bacteria and other reducing organisms in the sludge are stimulated to a maximum of activity possible within the non-thermophilic range. Under these conditions a stable and inoffensive sludge is produced in less than thirty days.

In order to operate a heated digester intelligently the operator must watch it carefully, especially during initial operation. He should keep an accurate record of all the factors entering into its operation, and he should be able to evaluate and interpret these records. However, a digester which has once reached balanced operation actually requires very little attention except normal routine work. The daily addition of raw sludge should of course be measured. In the case of the Belgrave digester the time of the pumping is noted and the volume computed. The sludge pumps are of the positive displacement plunger type. They have been checked frequently for volume of discharge when dewatering the tanks and show an error of about 6 per cent. Particular attention is paid to the packing glands of the pumps to keep this variation as low as possible. Digested sludge is measured on the beds. Samples of raw sludge are in general taken weekly and are composited during a pumping period. Samples of digested sludge are taken weekly from the tank and when pumping onto the beds. Analyses are made to show per cent total solids and per cent volatile matter. When pumping fresh solids to the tank a sample of the overflowing supernatant liquor is taken and similar analyses made.

Results of more than one year of operation show that the raw sludge has an average solids content of 5.5 per cent, 64 per cent of which is volatile matter. The overflow liquor averages a solids content of 0.18 per cent with a volatile content of 44 per cent. Digested sludge has an average solids content of 9.9 per cent with volatile content of 44 per cent.

During the first summer of operation (1935) before gas collection

and utilization equipment was installed, heating of the digester was discontinued to save fuel used in the auxiliary heater. The temperature at that time was 84 degrees F. and the pH was 7.0. The digested sludge in the tank had a volatile content of 46 per cent. As the temperature of the digester lowered it was noted that the pH of the digested sludge also went down, and the volatile content of the digested sludge gradually increased. Six months later (in November) the temperature had dropped to 58 degrees, the pH to 6.5 and the volatile had risen to 50 per cent. The sludge produced showed no visible evidences of these changed conditions but it was felt that trouble was not far ahead, so the heating system was started again. Twelve hundred pounds of lime was added to the digester (in the form of milk of lime) over a two-week period; the pH increased to 6.8. The temperature rise was slow due to inadequate heating facilities and the volatile content remained near 50 per cent. During December the temperature was raised to 77 degrees and the pH was increased to 7.0. The volatile content began to show a slight decrease and gas production became great enough to consider the installation of gas utilization equipment. A meter was obtained and measurements of the daily output recorded.

This information indicated that enough gas was being produced at least to heat the tank. A gas boiler was installed and connected to the digester heating system. A cross connection with the existing auxiliary heater was constructed, so that hot water could be drawn from it in the event of failure of the gas supply. Gas was conducted from the digester through suitable regulating and protective devices to the boiler. Twenty-four hour operation of this system soon raised the digester temperature to 85 degrees. The pH of the sludge remained at 7.0 and the volatile content dropped gradually to a low of 42 per cent. It has remained near this point to date. Gas production has been continuous and has varied between 1800 and 6000 cu. ft. per day, or from 0.6 to 2.0 cu. ft. per capita.

Ten to twelve hours of operation per day of the heating system was found to be sufficient to maintain a temperature of 85 degrees in the tank. Approximately 4000 cu. ft. of gas was being produced daily of which 2900 cu. ft. was consumed in the boiler and 1100 cu. ft. was burned in the waste gas burner. In view of the relatively large amount of gas being wasted it was decided to raise the digester temperature to 95 degrees and observe results. Twenty-four hour operation of the gas boiler soon raised the temperature of the sludge to 95 degrees. This temperature has been maintained for the last two months. No change in the pH was noted and gas production was seen to fluctuate widely, a maximum daily production of 6500 ft. being recorded. Total gas production over this two-month period dropped nearly 15 per cent as compared with production in the two previous months, when operating at a lower temperature. However, at the higher temperature the rate was 9.2 cu. ft. per pound of volatile solids added, as compared with a production of a little over 6.0 cu. ft. previously. The quantity of fresh solids added to the tank during the period of higher tempera-

ture was somewhat lower than the average and the volatile content was about 10 per cent lower. This accounts for the drop in total gas production. Digestion at 95 degrees is to be continued at this plant to check results now obtained.

A digester with fixed covers should be designed so that it is possible to pump raw sludge or sewage into the tank while digested sludge is being withdrawn. This is especially true where there is a continuous consumption of gas. At the Belgrave plant no such provision is made but it is possible to shut down the boiler while pumping digested sludge. A vent line from the gas dome to the atmosphere is opened and as the sludge level recedes in the tank, air is drawn in. After pumping is complete the sludge pumps fill the digester with raw sludge and sewage, displacing the air previously drawn in, except for a small amount in the gas dome above the sludge level. Gas is wasted into the atmosphere for at least an hour after the tank has been filled. Then the boiler is turned on again. No operating difficulties of any nature have been experienced while following this routine.

The digester is provided with a mechanical agitator of the Hardinge type. After balanced operation of the tank was attained the agitator was operated only during the day, and allowed to stand still overnight. When started up again in the morning a tremendous amount of gas was liberated at once which nearly extinguished the gas boiler. Continuous operation of the agitator was resumed and this resulted in a more uniform flow of gas.

The gas collection and utilization system requires considerable attention of a routine nature. Daily readings of gas produced, gas burned under the boiler, gas wasted, temperature of the feed and return water, quantity of water circulated, gas pressures in the main line, waste line and burner line and the temperature of the digester should all be recorded. The drip traps should be examined regularly to make sure that no stoppage exists which would prevent removal of condensation from the gas lines. The boiler temperature must be kept high enough to prevent condensation in the combustion chamber, but not so high as to cause excessive temperatures in the feed line to the digester. A tempering valve has been installed in the feed line at this plant to keep the feed water below a temperature of 130 degrees. However, if the boiler temperature is too high, water above 130 degrees will be forced by the tempering valve. The throttling valve in the gas line to the boiler should be operated manually at frequent intervals to prevent the valve stem from sticking. This is very important because if the gas supply should fail momentarily, extinguishing the pilot light, and if at the same time the thermostatic gas valve failed to close due to sticking, the boiler room would soon be full of gas.

Two years of operation of the Belgrave digester have demonstrated, at least in part, the following:

1. Although the optimum temperature is between 80 and 95 degrees F., operation at considerably lower temperatures is possible for a reasonable length of time without upsetting the balance of the tank.

2. Gas production should be figured in terms of gas produced per pound of volatile matter added to the tank and not on a per capita basis.

3. An operating temperature of 95 degrees F. results in greater gas production, but no change in pH or in the volatile content of the digested sludge.

OPERATION OF OPEN SLUDGE BEDS *

By William A. Ryan, *Sanitary Chemist, Rochester, N. Y.*

Historical

There are four sewage treatment plants within the city limits of Rochester, eleven treatment plants in operation in the towns and villages of Monroe County outside the city limits, and two plants in course of construction.

All the above mentioned plants, with one exception, have open sludge drying beds. The first plant to be constructed in Rochester was the Brighton plant, which was placed in operation on March 1, 1916.

The Irondequoit, or main treatment plant, was placed in operation April 1, 1917. The Charlotte and University plants are small treatment plants and were placed in operation in 1921 and 1924, respectively.

The first treatment plant in Monroe County was built at Brockport. This has since been replaced by a larger and more modern plant.

Descriptive

Usually a report of a sewage treatment plant will contain minute descriptions of the screens, tanks, trickling filter and other necessary appurtenances and will dismiss the sludge drying beds with a mention of the number or area.

In order to discuss the operation of sludge drying beds, a short description of the drying beds at the sewage treatment plants in Rochester and two nearby villages is in order.

The sludge drying beds at the Main plant in Rochester are 80 in number, each 40 ft. square, and arranged in four parallel rows. The original plans called for 40 beds, and the additional drying beds were constructed in 1935. The sludge is removed by hand labor and transported to the sludge dump in industrial railway cars.

The old beds are elaborate in construction, inasmuch as tracks are laid in two subways between the rows of beds, an electric gantry crane spanning the subway in which the cars are run. In the removal of sludge this crane lifts the body of an industrial car from its truck and places it upon the bed. The dried sludge is then shoveled into the car body by means of six-tine forks. The loaded cars are replaced on the trucks by the gantry crane and a train of four cars is hauled to the sludge dump by a storage battery locomotive.

The 40 new sludge drying beds are simpler in design inasmuch as

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the locomotive runs the cars onto the beds on permanent trucks, which run the full length of the 10 rows of beds. The beds are 19 in. in depth, built up as follows: The bottom 6 in. contain a mixture of No. 3 and No. 1 stone, and the bottom slopes towards the 3 in. vitrified drain tiles, which are laid 8 ft. apart, the next 8 in. layer is composed of 40 per cent coarse sand, with a 340 modulus and 60 per cent gravel under 4 in. in size. The next 3 in. layer is coarse screened sand, and the top layer of 2 in. is composed of fine sand washed and screened. The top sand should be sharp and clean as used in mixing concrete. To my knowledge there are no definite specifications for this top layer.

The 3 in. tile in the old beds drain into a depressed channel in the subways, while in the new beds the 3 in. tile drain into 8 in. vitrified tile set 40 ft. apart, the 3 in. tile (bell and spigot type with open joints covered with tarred paper) are laid east and west, while the 8 in. tile are laid north and south, with manholes at each end.

There are two drying beds at the Brighton plant, each 40 by 40 ft. The sludge is lagooned at this plant and the drying beds are not used at the present time. The smaller Charlotte and University plants have circular beds built around the Imhoff tanks.

At the Fairport plant there are five sludge drying beds with a total area of 8,310 sq. ft. to serve a population of 4,468. The beds are 20 in. in depth, the bottom 15 in. consists of bank-run gravel and the top 5 in. is washed sharp sand. The sludge is delivered to the beds by gravity through a concrete flume having a spillway and stop gate for each bed.

The beds are drained by means of 4 in. land tile set 3 ft. apart. The tile are laid in shallow trenches and covered with straw. The ends are also covered with tar paper. The tile drain into an 8 in. cast-iron pipe through which the water flows to Thomas Creek.

Provision was made for pumping the sludge from the secondary tank to the drying beds. This was found to be impracticable and a small drying bed was constructed adjacent to the secondary tank.

Brockport with a population of 3,500 has two sludge drying beds, each 20 by 60 ft., or 2,400 square feet total area. The gravel and sand on these beds is too fine and the operator experiences trouble in securing good drainage.

Operation

Inasmuch as the writer is familiar with the operation of the drying beds at the Main Treatment Plant in Rochester, an attempt will be made to draw a few definite conclusions from the operation data during the past twenty years. Table I shows the composition of the Imhoff sludge drawn onto the beds, as well as number of drawings each year.

Discussion

It will be observed from Table I that April 15 is the earliest date and December 21 the latest date on which sludge was drawn onto the drying beds. Any sludge drawn after October is left on the beds until spring.

TABLE I.—*Irondequoit Plant*

Year	Moisture, Per Cent	Depth, Inches	First Drawing	Last Drawing	Number of Drawings
1918.....		9	4/15	11/15	
1919.....		9	4/29	12/10	
1920.....		9	5/7	12/21	9
1921.....		9	4/24	10/19	11
1922.....	89.8	9	4/21	12/4	12
1923.....	91.6	9	4/20	10/31	13
1924.....	90.0	10	5/1	11/9	10
1925.....	90.8	10	5/13	9/25	9
1926.....	90.8	10	4/21	9/11	6
1927.....	91.9	8	5/18	9/12	10
1928.....	93.5	9	5/16	12/13	9
1929.....	92.7	9	3/28	9/28	11
1930.....	92.8	10	5/7	11/7	9
1931.....	93.7	10	6/2	12/8	10
1932.....	92.5	11	5/23	9/12	9
1933.....	94.0	10	5/11	10/5	8
1934.....	93.0	10	4/25	10/11	11
1935.....	93.4	10	5/2	10/10	7
1936.....	93.6	10	5/5	11/19	10
1937.....		10	5/7		14 to 10/1

Note: There have been occasional drawings of 12 inches.

Depths of 8–9–10–11 and 12 in. have been added, but 10 in. gives the best results. The dried cake will usually be 3 to 4 in. in thickness when forked off the beds. The thickness of air dried sludge is dependent upon the moisture in the sludge.

It will be observed that the moisture in the Imhoff sludge as drawn has steadily increased. This is due to an increasing amount of industrial waste, chiefly canning waste, which enters the treatment plant. The sludge-containing waste appears to dewater and dry as well as straight sanitary sewage sludge. The pH value of the sludge is consistently low, with an average of 6.5.

Table II shows the moisture in the air-dried sludge. This figure is dependent upon the temperature and humidity of the air. Percentages as low as 45 have been obtained, but the average is 60. There has been no trouble in disposing of the sludge for the past ten years. Under the heading of "Sludge Lagooned" there is a long story.

The sludge beds at the Main or Irondequoit Plant were designed on the general basis of 0.33 sq. ft. per capita. Under local climatic conditions, this has not been sufficient. When the Imhoff tanks were doubled the drying bed area was likewise doubled.

Because of increase in population this increase in drying bed area did not double the capacity. Furthermore the longer detention period in the tanks has practically doubled the amount of sludge to be handled.

There are many factors to be considered in designing drying beds. During the past ten years it has been necessary to lagoon from 5,000 to 12,000 cu. yd. of sludge each year. There is now in course of con-

struction an additional set of drying beds to the north of the plant. When these beds are completed it will mean that there will be 0.6 sq. ft. per capita based on a population of 320,000.

TABLE II.—*Irondequoit Plant*

Sludge Data for 1932

Moisture Determinations on Sludge from the Drying Beds

Date	Moisture Per Cent	Solids Per Cent
5/16	68.50	31.50
6/6	64.21	35.79
6/8	61.49	38.51
6/20	65.62	34.38
7/11	71.35	28.65
7/26	59.18	40.82
8/12	56.21	43.79
8/26	56.53	43.47
8/30	56.30	43.70
9/14	66.39	33.61
10/26	64.04	35.96
Mean	62.71	37.29

General

Total Sludge drawn from Imhoff Tanks.... 29,886 Cu. Yd.
Sludge drawn onto Drying Beds..... 24,840 Cu. Yd.
Sludge lagooned..... 5,046 Cu. Yd.
Sludge Removed from Drying Beds..... 7,135 Cu. Yd.

Revenue received from the sale of sludge..... $500.70

This represents 498 cars dumped into trucks and 555 loads shoveled from the dump.

In addition to the above, 650 loads were taken by the parks and schools. Approximately 1,200 cubic yards were used about the plant grounds.

May I add a word about the care of drying beds. It has been observed that approximately 1 in. of sand will be removed with the sludge cake per year of 10 removals. This lost sand must be replaced from time to time. The practice in Rochester is to add sand every 3 years. This sand should be a well washed sharp concrete sand somewhat coarser than the fine sand used in water filtration. It is advisable to rake over the beds after every removal and occasionally check the level of the beds.

Tables III and IV show the method of keeping records of amount of sludge removed, cost of removal and sludge analyses.

The short description of the drying beds at Brockport and of Fairport was included in order to point out the difference between inadequate and adequate drying bed areas. In addition to being inadequate, the sand and gravel at the Brockport plant is full of clay and fine loam

TABLE III.—*Irondequoit Plant*

Removal of Dried Sludge from Beds

New Beds, Removal No. 4, July, 1937

Date 1937	Beds No. ABCD	Cars	Man Hours
July 16	1	41	32
July 16	2	39	28
July 16	3	40	28
July 19	4	39	28
July 19	5	36	28
July 19	6	40	28
July 20	7	38	28
July 20	8	40	29
July 20	9	36	28
July 21	10	37	29
Total		386	286

386 Cars or 772 Cubic Yards Sludge Removed.
286 Man Hours @ 60¢ per Hour.
Total Cost of Removal $171.60
Cost of Removal per Cubic Yard ..... .222

TABLE IV.—*Irondequoit Plant*

Wet Sludge Data

1933

Tank No.	Per Cent. Moisture	Percentage—Dry Basis				Per Cent. Clear Water 24 Hours	pH Value
		Nitrogen	Volatile	Fixed	Ether Soluble		
1	92.2	2.28	54.6	45.4	10.4	47	6.4
2	94.1	1.99	50.0	50.0	12.0	52	6.5
3	95.1	2.58	55.0	45.0	9.6	50	6.4
4	93.9	2.56	53.1	46.9	10.8	51	6.4
5	92.1	3.36	54.5	45.5	12.2	48	6.4
6	95.5	2.30	53.6	46.4	10.9	55	6.4
7	94.9	2.45	54.3	45.7	9.8	48	6.4
8	94.6	2.27	54.1	45.9	10.1	56	6.4
9	95.3	2.12	55.6	44.4	8.6	57	6.4
10	92.2	2.02	53.9	46.1	7.9	54	6.4

which retards the drainage. The 1.86 sq. ft. per capita at Fairport allows ample drying bed area and causes no worry to the operator.

Experiments have been run in the laboratory to ascertain the volumetric decrease in moisture content of sludge which has dewatered in a graduate for 24 hours. The results show a drop of 10 to 12 per cent in volume, and the moisture in the dewatered sludge usually averages between 82 to 83 per cent.

The free water drains away in a well constructed bed within 24 hours; the combined water must evaporate through the heat of the at-

mosphere to a forking consistency. A well digested sludge drains better than a raw, partially digested or sour sludge. The gas bubbles rising through the sludge on the beds produces voids and aids in the drying.

Recommendations

In the northern part of America there are not more than six months in which sludge can dry on open beds. It is therefore suggested that 0.6 to 0.8 sq. ft. per capita be provided for open beds and 0.2 to 0.3 sq. ft. per capita for covered beds, to care for emergencies during the six months of non-drying weather. Otherwise, 1 sq. ft. of open bed space should be provided.

Care should be taken in the selection of stone, gravel and sand in order to obtain quick and thorough draining, and to provide ample underdrains which can be cleaned or flushed.

The use of chemicals, iron and aluminum salts, has proved of advantage in several plants, when added to sludge as drawn onto the beds. They are worth a trial. Two tons of iron and aluminum salts have been purchased for use at the Main Plant to hasten drying during October and November.

Remove sludge from beds as soon as possible after the sludge has dried.

Do not attempt to dry screenings or secondary sludge on beds used for drying primary sludge. Construct an additional bed for secondary sludge near the secondary basin.

If unable to dispose of or sell the sludge at time of removal, dump the sludge in a location which is easily accessible to wagons and trucks. This is very important.

If well screened, cinders may be substituted for sand, but the loss of material is greater. Lake sand is too fine and retards drainage.

OPERATION OF COVERED SLUDGE BEDS*

By Elvey A. Marshall, *Chief Operator, Sewage Treatment Plant, Geneva, N. Y.*

The following data covers a description of the glass covered beds at the Gulvin Park Treatment Plant, Geneva, N. Y. and reviews the method of their operation.

The sludge drying beds comprize two units approximately 150 ft. long by 40 ft. wide, which provide an area of 0.5 sq. ft. per capita. The necessary size of the beds is reduced 50 per cent by the provision of glass covers. Provision has been made for withdrawing small amounts of sludge from the digestion tanks at any desired time. This has been accomplished by dividing each bed into six parts.

The structure of the beds consists of a 6 in. layer of sand upon an 8 in. foundation of graded stone. This formation is underdrained by

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, N. Y., October 15–16, 1937.

a system of 4 in. tile on 6 ft. centers. Each bed is equipped with a monorail sludge handling system, which is provided with a chain hoist carrier and a 1 cu. yd. bucket. This handling system is so constructed that the bucket may be moved to any one of the bays located within the sludge bed.

The sludge is drawn into a sludge chamber from the digestion tank, from which it flows by gravity through an 8 in. cast iron pipe to a manhole, where it can be diverted to either bed by means of a slide gate. Then it flows through an 8 in. line into a concrete trough 10 in. square, which is located in the center of each bed and extends the length of the chamber. This concrete trough is provided with steel covers which serve as a walkway. These steel covers can be removed for cleaning the trough. It is also equipped with slide gates to permit the flow of sludge into the bay on either side of the trough.

The invert of the trough is elevated 12 in. above the top of the sand. In order to prevent the washing away of sand and stone at this point the sludge flows on to a concrete apron. The filtrate from the sludge drains back to the suction chamber where it mixes with the fresh incoming sewage.

In summer the bays are filled to a depth of 9 in. and in winter to a depth of 7 inches. We have learned from experience that we can operate most successfully at these stated depths. In summer approximately two weeks is necessary to dry the sludge to a moisture content of 50 per cent from an original solids content of 13 per cent. The dried sludge is approximately 3 in. in depth.

Our equipment does not include a method for heating the beds during the winter months, from November through March. For this reason the sludge dries very slowly. Four to six weeks during this period are necessary to approximate the result of two weeks of summer drying time.

Except during stormy weather, the ventilators are left entirely open in summer, but are closed in winter. If, however, good weather during this period warrants, they are opened during the day and closed at night.

The sludge is removed from the sand and placed into the bucket of the conveyor by means of coke forks. It is then elevated and loaded directly into trucks. This method is more advantageous than the common method of track installation as it presents no obstruction during the process of cleaning the bays and at the same time it saves unnecessary handling.

The sand after being raked free of any pieces of remaining sludge is then forked over, raked and leveled off. It is now ready for another application of sludge.

The sludge bed area is sufficient to accommodate withdrawals for a period of four months.

The following tests were made on dried sludge after its removal from the sand.

Moisture Per Cent.	Avg. Temp. F. Air	Max. Temp. Air	Min. Temp. Air	No. of Days
Summer 43	73	77	46	16
50	72	75	52	14
53	68	80	46	20
Winter 50	34	43	14	29
52	27	40	17	52

The following are some of the advantages of glass-covered beds:

Sludge can be withdrawn at any time from the digestion tanks. We believe that this is advantageous, because

a. Large amounts of sand and grit are present.
b. Digestion of the sludge is aided, in our opinion.
c. A more uniform production of gas may be maintained.

Interruption of the drying process is prevented.
Odors and flies are controlled.

The glass covers were supplied by Lord and Burnham. The total cost was as follows:

Glass covers	$15,057
Concrete foundations, division walls, trough, underdrains, excavations, sand, stone, etc.	9,455
Total	$24,512

Estimated Costs:

Population	22,500
Cost per capita	$1.09
Estimated cost of open beds	.84
Difference	$0.25

Editorial

ARE INDUSTRIAL WASTES LIABILITIES?

Conservation is the slogan of the day, whether it be of natural or industrial resources. Wanton waste is abhorrent to an enlightened civilization. If we have the ability to solve the intricate problems of production and improvement of industrial products, we should also have the ability to solve the problem of satisfactory disposal of wastes produced by such processes. It is frequently said by manufacturers that no methods of treatment are known for their wastes. As a matter of fact, there are probably technical means for treating all industrial wastes, and the only thing that stands in the way of the Utopia of wasteless industry is the question of cost. Every problem involves a balance of cost of disposal against the benefits obtained, and there is no sense or justice in demands for elimination of wastes from our streams and sewage treatment works, regardless of cost.

Fortunately, there are a few outstanding examples of industries which have profited by recovery of materials, once considered wastes, which now have commercial value. These few industries should be an incentive to the others, which still discharge residues of manufactured products to the sewers, to consider carefully the possibilities of recovering more of their raw materials. This consideration should not stop with a mere perfunctory analysis of costs and values, but research programs should be outlined, consistent and continuous studies should be undertaken in properly equipped chemical laboratories, and small-scale testing stations should be operated. Only in this way can industry convince the sanitary authorities that it appreciates the seriousness of the pollution of streams and lakes by industrial wastes.

When one considers the magnitude and complexity of the industrial waste problem, the few demonstrations of profitable recoveries of waste materials do not in truth give promise of widespread or prompt alleviation of the problem by profitable recovery of materials, but at least they prove that a careful study of the problem, as well as the expenditure of substantial sums of money has been well worthwhile for some plants. The three outstanding examples of successful recoveries of industrial wastes are the Corn Products Refining Company, located in the Sanitary District of Chicago, the Hiram Walker Distillery at Peoria, Illinois, and the U. S. Industrial Alcohol Company at Baltimore. It is significant that all three industries use similar raw materials, primarily carbohydrates such as molasses, starch, corn, rye and other cereals. Recovered products are stock feeds which always find a ready, although fluctuating, market. It seems logical to assume that in other types of industries, if the products are salable, the solids recovered or kept out of the wastes should also be salable, even though at a reduced value. However, in many processes the materials in the wastes are different from the salable products, because of chemical decompositions or syntheses used in the process.

A brief consideration of the progress in other industries of waste recovery indicates that recovery of more or less of the wasted materials may be possible, but finally some process of treatment allied to sewage treatment, or evaporation, may be required.

In the brewing industry, spent grains are generally recovered by dewatering in expellers, and steam drying. The expeller discharges a highly concentrated and putrescible liquor which adds considerably to the population equivalent of the wastes. Likewise, waste yeast and wort residues add to the organic load. A concerted study of improved methods of recovery would show results.

Yeast, vinegar and distillery wastes are a tremendous problem. The question of concentration of solids in the wastes now seems to be the dividing line between profitable and unprofitable recovery—but this question is the crux of all industrial waste problems. The fermentation industry is making a commendable effort to find out how much can be recovered within the factory. Jensen, in Denmark, has developed processes of treatment of these wastes, and the Standard Brands Corporation in this country has been carrying on intensive research for several years on the treatment of yeast wastes. Commercial Solvents Corporation has also studied the problem, and the Hiram Walker plant has installed and is operating equipment which is claimed to recover practically all of the organic solids. Other distilleries are making some effort toward a study of the problem.

The great meat packing industry produces probably the largest volume of the most putrescible waste in American industry, and for decades this waste has defiled streams and overloaded sewage treatment works, yet there has been no concerted effort to study the problem. Individual packers have made laboratory studies, but the industry's research center, the American Institute of Meat Packers, has done nothing. The once-vaunted boast that everything was recovered but the squeal never was true; the sewers carried away the evidence of other losses. However, some effort has been made by individual packers to alleviate this problem, notably at the Hormel plant in Austin, Minnesota. Unfortunately, the sludge proved to be toxic as a stock feed, and too greasy for a fertilizer, to confirm the earlier hopes of a valuable by-product, but this was the best effort that has been made by a packer to recover more of his waste materials.

Tanneries recover hair, but little effort has been made to recover lime, chrome salts or

fertilizer. The Tanners' Council started out bravely to attack the problem years ago, but not much has been heard from them recently. Treatment of tannery wastes has been studied at length, but little effort has been made to conserve waste substances within the tannery.

Paper mills have made great progress in recovery of fiber, but the basic sulfite and sulfate processes still discharge a large proportion of the weight of the wood as wastes. These wastes have probably been studied more than any other industrial waste, and hundreds of patents for recovery of materials have been granted, but as yet no satisfactory process has been developed. Sulfite waste is still a challenge to the most skilful efforts of research chemists. However, the Howard process has shown some promise. For fiber losses, the Adka process seems to be exciting the attention of technologists. After all has been done that can be done within the paper factory, there will still remain waste waters that may require further treatment.

Other organic wastes, from canneries, wineries, and beet sugar works, are widespread and the losses are staggering, but in this field there are so many small plants that attention should first be directed to the larger ones. For isolated seasonal plants, Warrick has reported progress in treatment, but the brief season in most canning operations makes for inefficiency in recovery of solids in the factory. The tremendous losses of tomato solids from the large tomato canneries are astounding. Surely this is a fertile field for the best efforts of research chemists.

Dairy wastes are ubiquitous, and consequently have been subject to widespread study. Agar, in this issue, reviews the work that has been done on these wastes. Recovery of salable byproducts is encouraging; treatment of residual wastes is feasible and practical.

The steel and chemical industries are of less importance as producers of industrial wastes, if we except the by-products coke plants. In the steel works, pickling liquor is practically the only waste of importance. This has long been a subject of concern and research, and everyone agrees that the ferrous sulfate should be recovered, but it has been hoped that better technique might be developed in the recovery process, to cut down costs and improve the product. A great advance has been reported in Germany in methods of recovery, and a comprehensive symposium held at the meeting of the Association of German Steel Workers in Düsseldorf in February, 1937, indicated that several improved processes for recovery of copperas and ferrous sulfate (monohydrate) are being used in Germany.

Phenol wastes from by-products coke plants are probably most widely publicized and condemned of any industrial wastes because of their effect on the taste of public water supplies. The progress that has been made in the extraction of phenols from these wastes is well-known, and processes are available that will remove 90 per cent of the phenols from such wastes. It is not generally realized, however, that only about 70 per cent of the B.O.D. is removed by such processes, leaving a substantial residual waste that will affect the oxygen balance of streams and the loading of sewage treatment plants.

Chemical wastes are of infinite variety, but on the whole they are of less serious significance than those just discussed. Large tonnages of acids can be discharged into sewers or streams, if care be taken to balance the acidity against the available alkalinity of the sewage or water, and uniform discharge of acid be provided. Precipitation, aeration or evaporation within the plant may result in substantial reduction of wastes.

In this brief review of the status of some industrial waste problems, it is apparent that such wastes are almost universally liabilities to the sewer authority, but they may not be liabilities to the manufacturer. After entrance into the sewer, hope of profitable recovery practically vanishes. Therefore, industry should exhaust every possibility of recovery within the factory by establishment of research groups of chemists and engineers charged with the responsibility of determining what improvements of processes and recoveries of materials may be accomplished. The time is short before pressure for alleviation of pollution by industrial wastes becomes urgent. National legislation may not condone local complacence; therefore, if industry has to spend money for waste treatment, it would be wise to start now to study how such wastes may be diminished in volume and strength.

F. W. M.

Reviews and Abstracts

H. W. STREETER

THE OCCURRENCE OF DILUTE SEWAGE AND ITS RATIONAL TREATMENT

BY H. C. SHENTON

The Surveyor, **92**, 629–630 (1937)

It is pointed out that in many cases the volume of sewage treated is much greater than is usually assumed, because in the smaller treatment plants, such as are found in conjunction with hospitals, factories and small towns, there is no attempt to make a careful gauging of the sewage flow.

The dilution of the normal flow of sewage may be caused by rainfall or the infiltration of ground water. The flow that is ordinarily spoken of as the "dry weather flow" is not the "normal" flow but the minimum flow. For example, gaugings of the dry weather flow of sewage from a town of several thousand were taken and found to be 212 gal. per capita per day. As there were no trade wastes present, and taking the daily normal flow per capita or 30 gal., it is seen that the dilution was approximately seven times. This sewage, according to McGowan's formula, had a strength of 27.5 which classifies it as a dilute sewage, and by removing the settleable solids from such a sewage very little additional treatment is necessary.

It is suggested that in the treatment of a dilute sewage the settleable solids be removed as soon as possible to prevent their further solution and also to prevent occurrence of septic conditions.

The degree of dilution affects very markedly the volume of sewage that may be treated per cubic yard of filter per day. According to the Royal Commission, a strong sewage from which only the detritus has been removed requires 1 cubic yard of filtering medium per 15 gallons treated per day. Twenty-five gallons of a sewage of average strength or 40 gallons of dilute sewage can be treated per cubic yard per day. It is common practice to discharge a sewage without treatment after a dilution of six volumes has taken place. It is pointed out that by dilution a sewage may be treated at an increased rate.

The removal of the settleable solids is generally accepted as being a prerequisite to the further purification of a sewage, yet the use of the old-fashioned settling tank in which the sludge may be removed only once a week is shown to be ideal for increasing the strength of the sewage passing through it. In the treatment of a dilute sewage the frequent removal of sludge as an aid to purification is emphasized.

In conjunction with the removal of settleable solids, mechanical or chemical flocculation, together with clarification, may be resorted to during those periods when further treatment is advisable. This should be more economical than designing a works suitable to handle a sewage during the dry weather flow and ignoring the fact that during the greater part of the year only a dilute sewage is being received.

W. ALLAN MOORE

EFFICIENCY OF HUMUS SETTLING TANKS

BY P. G. LLOYD

The Surveyor, **92**, 621 (1937). (Discussion) *The Surveyor*, **92**, 621–23 (1937)

An attempt was made to measure the efficiency of two humus settling tanks connected in series (each tank being 66 ft. by 35 ft. by 6 ft. average depth) by determining

the increase in albuminoid ammonia and oxygen consumed between a settled and shaken sample of the effluent. The surface flow rate on normal peak days was about 6 ft. per minute.

A table is given showing the results obtained on catch samples over a period of three years. The values for the increase in per cent between the shaken and settled samples range from 36.7 to 131 for the albuminoid ammonia (the latter value being obtained when the flow was three times the D.W.F.). The oxygen consumed values range from 7.5 to 83.3 per cent.

Discussion.—Mr. A. Kershaw (chairman) brought out the idea that one objective of Mr. Lloyd's work was to evolve a standard for designing humus tanks.

Mr. A. Holroyd (Dagenham) stated that a settling tank could not be designed on the basis of so many hours' detention time but that detailed flow measurements were necessary.

Mr. L. F. Mountfort (Edmonton) objected to the use of the word "efficiency" as used by Mr. Lloyd. He stated that in order to determine the efficiency of any piece of apparatus one must know not only the output but the input as well and that Mr. Lloyd had concerned himself only with the output. The purpose of an efficiency figure was to enable one piece of apparatus to be compared with another, but, that the figures arrived at by the author could be used only for different tanks carrying exactly the same bacterial bed effluent.

Dr. H. T. Calvert (Ministry of Health) stated that Mr. Lloyd was really determining the "inefficiency" of the humus tanks and therefore the efficiency.

Mr. C. H. Hamlin (Linton) again brought out the idea that in order to measure efficiency one must know both the input and the output of the tanks.

Mr. E. Hodson (Croydon), commenting on the design of tanks, said it would be impossible for an engineer to design a humus tank without knowing the rates of flow and that the efficiency of such a tank should be determined by the amount of suspended solids that were removed.

Mr. J. T. Calvert (Westminster) agreed that while some of the figures presented were not a measure of the efficiency of the tank, nevertheless, the results obtained were a measure of how far below perfect settlement he was getting.

W. Allan Moore

CONCRETE AND ITS USES IN SEWAGE DISPOSAL WORKS

By Richard H. Osler

The Surveyor, **92**, 521 (Oct. 29, 1937). (Discussion) **92**, 571–72 (Nov. 12, 1937)

The article is an abstract of a paper presented at a Midland Branch meeting of the Institute of Sewage Purification on October 23, 1937. The author discusses the various tests for aggregate, including screen analysis, and tests for organic matter, and devotes considerable space to a discussion of the quantity of water needed to produce a dense concrete of high compressive strength, recommending the use of the slump cone test in the field to determine the correct quantity.

A section of the paper is devoted to the possible deleterious effects of sewage on concrete. Reference is given to tests made by partially submerging for twelve months cubes of concrete composed of Portland and high-alumina cements in sewages of various strengths. It was found that the denser concretes of both classes were unaffected, whereas the more porous concretes were attacked. The author points out that hydrogen sulfide attacks concrete and says that this trouble can be avoided by proper design to release the gas and also mentions the use of bituminous protective coatings.

Discussion.—Much of the discussion was concerned with questions relating to the mixing and placing of concrete.

Mr. W. Clifford asked for Mr. Osler's views on the softening of concrete which was occasionally found in sewers and sewage works and referred to the Cairo (Egypt) main outfall sewer as an example.

Mr. D. H. A. Price spoke of the problem of sulfates in ground water and asked whether their presence invariably caused an attack on concrete or if there were other factors involved.

Mr. J. Hurley asked for an account of the properties of sulfur base cements and if they were capable of resisting the attack of hydrogen sulfide. He said that his experience was that the liquid flowing in a sewer was alkaline but that acid conditions prevailed in the air space above the liquid and that it appeared that high-alumina cement was more resistant to acid than Portland cement, but unfortunately less resistant to alkali. He also inquired if pitch were better than bitumen for coating sewers and channels because of the remote possibility of cracking.

Mr. Osler, in reply, said, regarding the surface softening of concrete, that it depended on the porosity of the concrete. There was, however, another factor sometimes encountered and which was quite common in the Scandinavian countries where the water was very soft, namely, that the water dissolved the cement at the surface of the concrete. This action was intensified by storage of a soft, slightly acid water. The cause of the trouble with the Cairo main outfall was agreed to be hydrogen sulfide that had no chance to escape.

In reply to Mr. Price's question concerning sulfates in ground water, he said that this problem was a serious one and usually high-alumina cement was used where sulfates were present to a dangerous degree. The engineer could save money by putting 4 to 6 inches of high-alumina cement concrete on the outside and filling in with Portland cement concrete or by coating Portland cement concrete with bituminous paint where possible.

Mr. Osler said that he had no information on the sulfur base cement that Mr. Hurley asked about. What Mr. Hurley had said about the action of acids and alkalies on the two classes of concrete was true. Concerning bitumen versus pitch—bitumen was much more frequently specified and there should be no danger of attack if the bitumen were properly applied.

R. S. SMITH

SOUTHAMPTON'S NEW SEWERAGE AND SEWAGE DISPOSAL WORKS

ANON.

The Surveyor, 92, 507–09 (October 29, 1937)

The new Southampton sewerage system and treatment plant which was put into operation in October, 1937, serves the western part of the borough and two adjacent parishes, a total of approximately 2,250 acres. The sewers total 10,400 yards in length, varying from 18 inch to 51 inch diameter, including 1,100 yards of 33 inch cast iron sewer in waterlogged ground alongside a stream.

The purification works provide only partial treatment, though a considerable area is reserved for filters. All sewage flows to the plant by gravity and through mechanically operated screens to the pump well. Screenings are carried by belt conveyor and skip to a suitable part of the site for burial or to a barge for disposal at sea. Grit pockets are provided and the grit is handled mechanically and disposed of in a similar manner to the screenings.

The centrifugal pumps are of the vertical, nonclogging type, consisting of three 10-inch units, each with 1,700 g.p.m. capacity, two 18-inch units, each with 5,000 g.p.m. capacity, and two 24-inch units, each with 10,000 g.p.m. capacity. The pumps are normally float-operated, but may be manually controlled from push-button stations. The connections from the float switches (three in number) are brought to the motor starting panels through a plug board which enables the attendant to select the combination of pumps best suited to the prevailing conditions. Each pump, when started by rising water operating the float switch, automatically shuts down its smaller predecessor. These pumps deliver the sewage through a standing wave flume recorder to

detritus tanks, which discharge either into a storm by-pass or by gravity to the eight settling tanks, each 100 ft. long, 40 ft. wide and with an effective depth of 8 ft., providing 15 hours' detention period.

The sludge from the detritus and settling tanks flows by gravity to the pump house where it is lifted by a pair of 250-gallon capacity compressed air ejectors to an elevated storage tank. From here it flows through a pipe line and is delivered under seal into specially constructed sealable barges for disposal at sea.

R. S. SMITH

TREATMENT OF RAYON BOIL-OFF WASTE

BY FOSTER DEE SNELL

Ind. Eng. Chem., 29, 1438-39 (1937)

Two satisfactory methods for the treatment of rayon boil-off waste are described. The main ingredients of the waste are sodium carbonate, alkali metal soaps, and emulsified mineral oil, and the volume to be treated is estimated at 60,000 gallons per day.

The first method described makes use of calcium chloride which converts the soaps present to the insoluble calcium soaps and the soda ash to calcium carbonate. The sludge formed, which entrains the mineral oil, may be removed by filtration on a light cotton fabric. The rate of filtration is about 1 gallon per 90 sq. ins. of filtering media per minute, so on a commercial scale about 1.25 sq. ft. of filter area is required per 100 gallons per day. The effluent is clear and harmless to fish and animal life.

The second method, and the one in use at present at Sparta, Ill., consists in filtering the raw boil-off liquor through a bed of ashes 3 ft. deep. The ashes apparently contain soluble heavy metal salts which cause precipitation of the alkali soaps and since the stability of the emulsion is broken the mineral oil is also precipitated.

In practice the filter bed used is 3 ft. deep and contains 1,440 cu. ft. or 30 tons of ashes. It is divided roughly into three sections, the oldest section being renewed each week, with disposal of the ashes for secondary road construction. Each charge of 30 tons of ashes treats approximately 1,000,000 gallons of boil-off waste. It is estimated that this volume contains 6,500 lbs. of oil and 1,500 lbs. soap, soda ash, etc.

In Table I are given the results obtained by these two methods of treatment. The results reported in which calcium chloride is used can not be compared directly because of the increase in solids resulting from the addition of salts in the treatment. The effluent from the ash treatment still contains much suspended matter but is clarified considerably over the original condition.

TABLE I.—*Results of Trade Waste Treatment*

(Parts per million)

	Raw Liquor	2 Lb. $CaCl_2$ per 100 Gal.	4 [illegible]. $CaCl_2$ per 100 Gal.	Filtered through Bed of Ashes
pH	106	7.6	7.2	7.0
Total solids at 110°C	6680	3940	7390	2410
Inorganic solids (by loss on ignition)	3080	3330	5090	2160
Organic solids (by difference)	3600	610	1300	250
O_2 consumed (permanganate method)	3760	*	*	660

* Not significant because chlorides are present.

W. ALLAN MOORE

THE DETERMINATION OF DISSOLVED NITROGEN IN WATER

By Norris W. Rakestraw and Victor M. Emmel

Ind. Eng. Chem. Anal. Ed., 29, 344–46 (1937)

A gasometric procedure, together with a cut of the apparatus used, is described for the determination of dissolved oxygen and nitrogen in water.

The water sample is drawn into a calibrated bulb of 100 ml. capacity. From this measuring bulb the sample is forced at a high velocity through a jet of about 0.5 mm. diameter into an evacuated bulb (previously evacuated by filling with mercury and then lowering the mercury level) of 300 ml. capacity. The water sample is then drawn back into the measuring bulb and the extracted gas forced up into a drying tube by raising the mercury reservoir. The drying tube, evacuated by means of an oil pump, contains ascarite, calcium chloride and dehydrite in the order named to remove carbon dioxide and water vapor. The water sample is circulated through the vacuum bulb at least four times, the extracted gases being forced into the drying tube after each treatment, to insure the complete removal of all dissolved gases.

The manometer connected with the line through a mercury pump is read and the gas is then drawn from the drying tube in two operations and forced into a small bulb, of 1.5 to 2.0 ml. capacity, the volume of which has been determined before sealing into the line. The volume of extracted gas is then read manometrically, the mercury level being brought to a predetermined level.

By means of the mercury pump the gas is forced into a reaction chamber containing freshly cut phosphorus. The phosphorus is melted by gentle heating and the gas allowed to react for about five minutes, after which the remaining gas is pumped out of the reaction chamber and then returned, when it is allowed to react for a few minutes longer.

The deoxygenated gas is pumped back into the storage bulb and the volume again read manometrically. The gas is then pumped into a second reaction chamber where it is allowed to react with metallic lithium contained in a steel cup, the lithium being heated above its melting point.

The residual gas, after cooling, is pumped back into the storage bulb and its volume again read manometrically. From the four pressure readings and knowing the laboratory temperature and pressure and the volume of sample taken it is possible to calculate not only the total amount of gas dissolved per liter but also the volumes of nitrogen and oxygen.

The table given shows how the values obtained by this method (using sea water) check with those as determined by the Winkler method.

Removal of Oxygen

O_2 by Extraction ml./l.	O_2 by Winkler ml./l.	O_2 by Extraction ml./l.	O_2 by Winkler ml./l.
4.45	4.46	4.31	4.28
4.85	4.89	5.12	5.12
5.01	4.94	5.15	5.20
4.60	4.52	5.42	5.54
4.76	4.71	Av. 4.85	Av. 4.85

W. Allan Moore

POLLUTION OF STREAMS BY COAL MINE DRAINAGE

By Willard W. Hodge

Ind. Eng. Chem., 29, 1048–55 (1937)

The opening of the coal mines in Pennsylvania, West Virginia, Ohio and neighboring states resulted in many of the formerly alkaline streams becoming acid.

Bills were introduced in Congress to prevent acid pollution of navigable waters as early as 1899 but many studies and surveys since have indicated a progressive increase in the acidity of many streams in this area. These streams (Monongahela, Allegheny, Ohio) flow through a highly industrialized region and studies have shown that acid from hundreds of iron and steel mills and acid sludge from oil refineries are also discharged into them. It is estimated that 90 per cent of the acid in the rivers comes from acid mine drainage. From Federal and state stream surveys it has been estimated that the equivalent of 3,000,000 tons of concentrated sulfuric acid per year were contributed by acid mine drainage.

This acid load of the stream results in a very obnoxious and destructive type of pollution. The acid water causes excessive corrosion to navigation works, ships, bridges, pipe lines, etc. The acid, iron sulfate and iron oxide often destroy fish, interfere with natural purification and make the water unfit for household or industrial use. The annual losses, due to corrosion, "red water" problems and additional costs for treating water supplies have been estimated at $10,000,000.

It has been shown that the production of sulfuric acid in coal mines results from the moist oxidation of iron sulfides, pyrites and marcasite and "sulfur balls" present in the coal. The equations given for the principal reactions involved are:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4 \quad (1)$$

$$4FeSO_4 + 2H_2SO_4 + O_2 = 2Fe_2(SO)_3 + 2H_2O \quad (2)$$

$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4 \quad (3)$$

Temperature and fineness of coal affect the rate of pyritic sulfur oxidation in coal. The essential factors are the exposed surface area of sulfur-bearing material in the mine, the concentration of oxygen in the air in the mine, the dissolved oxygen content of the water films in contact with sulfur material and the rate of removal of the sulfate formed. Analyses of mine waters vary over a wide range reaching a pH in some cases as low as 1.7 and an acidity to phenolphthalein as high as 29,600 p.p.m.

Some methods developed for reducing the mine acid pollution of streams include

(1) Impounding the mine drainage;
(2) Flooding abandoned mines;
(3) Neutralizing the acid with limestone or other materials;
(4) Completely closing the mine;
(5) Chemical processes for the recovery of byproducts;
(6) Dilution of mine drainage;
(7) Diverting acid drainage to streams hopelessly polluted;
(8) Air sealing abandoned mines and worked out entries in active mines;
(9) Diversion of surface water from entry into mines.

The last two methods are the only ones of sufficiently low cost and effectiveness for combating stream pollution by acid mine wastes.

In 1933 a regional program for sealing acid producing abandoned mines was started under the supervision of the U. S. Public Health Service in co-operation with the states in the Ohio basin. Sealing consists in closing the mine openings so that the drainage in a mine can flow out through a water-sealed trap and so that all air and surface water are prevented from entering. The funds for this work were obtained from the C. W. A., the F. E. R. A. and the W. P. A. The health department of each state has charge of the mine sealing within its borders. The organization procedure and methods of sealing

mine openings are described. The average costs of sealing in West Virginia are reported as follows:

	Per Opening	Per Mine
Construction	$ 89.00	$798.00
Maintenance	16.00	144.00
Total	$105.00	$942.00

Within three and one-third years over 47,000 openings and 13,500 abandoned coal mines have been sealed in the entire region. The value of the sealing program is illustrated by the results at a typical Pennsylvania mine where the drainage was reduced from 105,000 gallons per day containing 3,000 pounds of sulfuric acid to 32,000 gallons containing only 200 pounds of acid. In Ohio the program has decreased the production of mine acid by more than 375,000 pounds per day and in West Virginia by about an equal amount. As a result many municipalities have reported marked improvements in their water supplies and more than a thousand miles of streams have had their acid loads reduced. A good bibliography is appended.

C. C. Ruchhoft

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